In Situ Bio-Optical Observations on NERACOOS Buoy A01 (2005-2017): multichannel calibrated chlorophyll fluorescence, turbidity, and multispectral incident irradiance and upwelling radiance

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In Situ Bio-Optical Observations on NERACOOS Buoy A01 (2005-2017): multichannel calibrated chlorophyll fluorescence, turbidity, and multispectral incident irradiance and upwelling radiance

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SUMMARY

This report describes the past year of work under MWRA's continuous biological monitoring in Massachusetts Bay and the resulting findings. The program focus is field sampling of marine algae (chlorophyll concentration), to monitor water quality conditions. This monitoring is required by the Ambient Monitoring Plan attached to the National Pollutant Discharge Elimination System (NPDES) permit that MWRA holds for discharging treated effluent from the Deer Island Treatment Plant through its outfall in Massachusetts Bay.

Bowdoin College is contracted by MWRA to collect measurements of both chlorophyll and turbidity in real time from sensors on a buoy sited off Cape Ann in northeastern Massachusetts Bay, then analyze and report the results annually. The University of Maine operates and maintains the buoy, with support from the Northeast Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and from a separate MWRA contract. The chlorophyll and turbidity sampling began in 2005 and MWRA now has approximately 12 years of hourly observations in its database.

Results from the past year show that conditions in 2016-2017 were typical of other years and did not indicate unusual water quality. Based on all 12 years of data, the typical seasonal cycle in chlorophyll includes primary and secondary peaks in spring, and a fall peak as well. Turbidity conditions vary more from year to year than chlorophyll, but generally include higher values from late winter through spring, and an early fall peak.

Improved post-processing methods were developed, including handling of calibration drift, non-photochemical quenching (NPQ), and outliers. They were implemented on the new 2016-17 year of data and also on data from all prior years. This improves the data in MWRA's database, and therefore improves all analyses that use them. Furthermore, the first year of irradiance observations, important to improve NPQ corrections, was completed.

The program relies on two identical sets of sensors; as each deployment starts one set is replaced by the other, in order to maintain continuous real-time measurements. Each set of sensors is cleaned and maintained when it is not deployed. Typically, University of Maine redeploys the buoy every 6 months, because during longer deployments the data return is reduced due to biofouling of the sensors. The most recent deployment had an atypical schedule, lasting 12 months from July 2016 to June 2017. This resulted in significant bio-fouling, causing a gap in the record several months long starting in late 2016. Limiting the duration of future deployments to approximately 6 months remains a top priority.

Fortunately, during this deployment Bowdoin had installed a redundant second chlorophyll sensor they own, as a test. The second sensor has a newer anti-biofouling system, which lasted nearly all 12 months without fouling, meaning a long gap in 2017 was avoided. The better performance of the newer sensor was demonstrated clearly because it was a head-to-head comparison (same buoy, depth, and deployment conditions) against the standard sensor.

In addition to better anti-fouling, the redundant second fluorometer improves on the traditional sensor by including multiple channels. This provides new information about phytoplankton community structure. Results from 2016-2017 suggest community dominants were cyanobacteria in winter, dinoflagellates in summer, and diatoms in spring and fall.

Introduction

The bio-optical observing program for the Cape Ann buoy (NERACOOS Buoy A01, operated by UMaine) is founded on a two-channel sensor measuring chlorophyll fluorescence and turbidity (the latter calibrated for both turbidity and particle backscattering units). It was initiated October 22, 2005 so there is now a data archive of nearly twelve years of hourly observations. The most recent deployment processed, A0136, had an atypical schedule, lasting for approximately twelve months (July 2016 through June 2017). This presented challenges for the sensors because of biofouling. This deployment was also unique in that in addition to the same two-channel sensor as in past deployments, three new sensors were deployed in a standalone configuration. The new observations include chlorophyll from a three-channel excitation fluorometer, above-water downwelling multispectral irradiance, and near-surface upwelling multispectral irradiance. The focus of this report is on the incremental addition of the deployment A0136 standard two-channel bio-optical observations to past years' data, and the establishment of the new observational data set. Descriptions of the flagging and data correction protocols, daily statistics and an analysis of the most recent year's phenology are provided.

Methods

As explained in prior reports (e.g. Roesler 2016) the WETLabs ECO FLNTU two-channel sensor is the standard bio-optical device that has been deployed on Buoy A01 since 2005. In order to provide continuous observations with no gaps between deployments, two such sensors are dedicated to the observational program; they are swapped on/off the buoy at the start of each deployment, so at all times one is in the field and the other is on shore. Each of the two FLNTU sensors is serviced and calibrated by the WETLabs factory when it is on shore in between its deployments. This sensor is integrated into a WETLabs DH4 data handler that provides power to the sensor, controls sampling, archives the raw observations of each hourly burst sampling and provides hourly mean and standard deviation values to the Campbell data controller which, in turn, incorporates it into the real-time data stream available via the real-time data portal (http://gyre.umeoce.maine.edu/data/gomoos/buoy/html/A01.html).

During this past deployment, A0136, three additional sensors were deployed in an experimental configuration integrated into the same DH4. However, these additional data are not transmitted in real time due to limitations on the Campbell software set up. We are in negotiations with UMaine to upgrade their software to accommodate the additional data streams; on other NERACOOS buoys, this has been done for many years. Without real time observations, there is a significant time lag for processing as instruments must be recovered from the buoy, transported to Bowdoin College, cleaned, downloaded and post-processed.

The additional sensors include a custom made WETLabs ECO Triplet sensor FL3-WB that consists of 3 excitation channels (435nm, 470nm, 532nm) and one emission channel (695nm) to detect chlorophyll fluorescence stimulated by different pigments that absorb in the three

wavelength bands. This sensor has been used to detect changes in phytoplankton community composition in Maine Lakes (Proctor and Roesler 2010), the Arabian Sea (Thibodeau et al. 2014), and in the western Mediterranean Sea (Roesler et al., 2017). Second, a Satlantic OC507-ICSA seven-channel irradiance sensor was deployed on top of the buoy and connected to the subsurface DH4 via a long cable through the well of the float. This sensor is factory calibrated and provides hourly estimates of incident downwelling irradiance ($\mu W\ cm^{-2}$). Third, a Satlantic OC507-ICSW-R10 seven channel in-water radiance sensor with 10^{o} solid angle detection was deployed in an downward viewing configuration to measure nadir upwelling radiance ($\mu W\ cm^{-2}\ sr^{-1}$) at the depth of the bio-optical frame (3m). This sensor was also factory calibrated.

Recent work has concluded that the factory calibrations of the WETLabs ECO model chlorophyll fluorometers are biased by a factor of 2 (Roesler et al., 2017). For this reason, Bowdoin laboratory calibrations for the chlorophyll fluorometers have always been implemented for buoy A01. All fluorometers are calibrated in the lab prior to deployment using ten dilutions of a monospecific culture of the diatom *Thalassiosira pseudonana* (Proctor and Roesler 2010). The culture is grown in nutrient replete L1 media at an irradiance that maximizes growth rates (i.e. ~300 μEin $m^{-2}\ s^{-1}$) and minimizes pigment packaging due to low light acclimation. The culture is harvested in exponential growth with maximal extracted chlorophyll concentrations between 20 mg m^{-3} and 50 mg m^{-3}. This approach to calibration provides a transfer function between sensors and between a single sensor over time, accounting for variations in sensor gain, and also provides conversion of the signal from digital counts (millivolts) to biogeochemical units (mg m^{-3}). Because the excitation wavelength (470 nm) does not directly stimulate chlorophyll fluorescence, it is not possible to calibrate with a standard dilution of purified pigment. In vivo fluorometers take advantage of the energy transference between accessory pigments in the light harvesting complexes to chlorophyll *a* by stimulating accessory pigment absorption at 470 nm. While the fluorescence yield (fluorescence per extracted chlorophyll) varies between species, as a function of environmental acclimation, growth phase, and non-photochemical quenching, each of these sources of variability can be assessed on long-term time scales of observations and thus the impacts can be minimized or exploited for further information (Roesler and Barnard 2013).

Post-processing of the real-time data for quality control is a five step process.

Step 1. Correction for sensor drift. Offsets between recovery/deployment of sensors, that appear in the real time data as step functions, are evaluated by post recovery calibration and/or by identification of offset relative to prior and subsequent deployments. The offsets are flagged and the data are corrected. Note that as this is first deployment for the irradiance sensors, there is no offset correction.

Step 2. Removal of biofouled data. Biofouling is identified by a logarithmic increase in signal to values determined to be out of range or saturating for the sensor. The biofouling takes two forms: the first is a smooth increase associated with biofilm growth, the second is an increase

associated with extreme hour-to-hour variability due to structural growth on the sensor such as seaweeds that contaminate both the fluorescence and turbidity signals as they waft in and out of the optical sensing volume. The biofouled observations are flagged as either biofilm or structural and removed from the data stream.

Step 3. Removal of data impacted by non-photochemical quenching (NPQ). NPQ of chlorophyll fluorescence is observed in the surface waters under saturating irradiances. The effect decreases exponentially with depth. At the surface the onset occurs as early as dawn and the recovery is prior to sundown (e.g., approximately 5am and 8pm local time, respectively, in July), as seen in Figure 1.

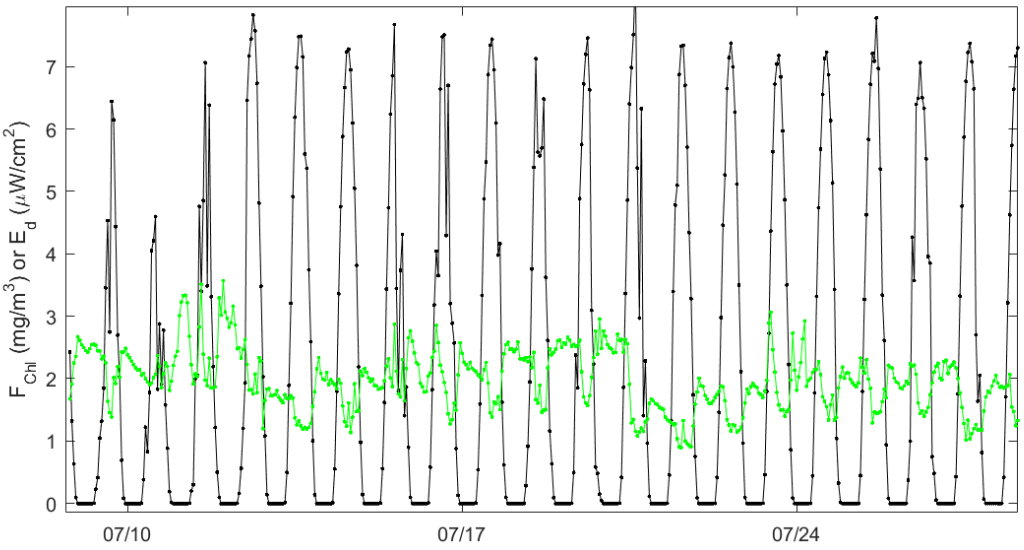

Figure 1. Example of non-photochemical quenching. Irradiance (black) and chlorophyll fluorescence (green) data streams from the Satlantic OC507 ICSA at 490 nm and WETLabs FLNTU, respectively, during a portion of July 2016.

At present it does not appear to be possible to identify a specific irradiance level that coincides with the onset of NPQ. (However, the data set is now available for future investigation of this question, which is a priority). Therefore, chlorophyll fluorescence observations during all daylight hours are currently flagged as NPQ-impacted and removed from the data stream for both fluorometers.

Step 4. Removal of single value outliers (SVO). SVOs are identified as differences between successive consecutive measurements that exceed the coefficient of variation and are in excess of 15 mg/m^3 (chlorophyll) or 3 NTU (turbidity). SVOs are flagged and removed from the data streams. A new strategy is being developed to identify SVOs in the irradiance data streams by computing a clear sky modeled time series of irradiance for each wavelength and comparing it to observations; those values exceeding the clear sky value will be flagged. It is not currently implemented.

Step 5. Identify values below minimum detection levels. The minimum detection levels (MDLs) of the chlorophyll, turbidity, irradiance and radiance sensors are 0.05 mg/m^3, 0.05 NTU, 0.06 μW m^{-2} and 0.0003 μW m^{-2} sr^{-1}, respectively. Observations below -1*MDL are flagged and removed. Values between -1*MDL and 0, and those between 0 and +1*MDL, are independently flagged, for convenience of entering the data in the MWRA database where different value qualifiers are applied to the two ranges. The negative values between -1*MDL and 0 are not removed because removing negative values within an MDL of zero leads to positive biasing of the observed data (Thompson 1998).

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 FL3-WB chlorophyll fluorometer (F1 through F3),
- the 7-channel irradiance (ED7), and
- the 7-channel radiance (LU7) sensors.

The appendix provides data string formats. Table A1 provides the data string for hourly chlorophyll fluorescence data asci files (BuoyA_HChl_2017.dat for the FLNTU, and files BuoyA_HF1_2017.dat, BuoyA_HF2_2017.dat, and BuoyA_HF3_2017.dat for the 3 channels of the F2WB, respectively).

Table A2 provides the data string format for the turbidity data (ascii file BuoyA_HNTU_2017.dat).

Table A3 provides the data string format for the hourly downwelling irradiance and upwelling radiance data ascii files (BuoyA_HED7_2017.dat and BuoyA_HLU7_2017.dat, respectively).

Table A4 provides the data string format for the daily chlorophyll data file (BuoyA_DChl_2017.dat) and the daily turbidity file (BuoyA_DNTU_2017.dat). These files include daily statistics of FLNTU data, calculated from the final data column in the hourly chlorophyll fluorescence file (column 21) and hourly turbidity file (column 19), respectively.

A Matlab binary storage “mat” file is provided corresponding to each of the asci files, with the same filename but file extension “.mat” instead of “.dat”.

Results

Most recent deployment A0136

The time series of the internally recorded bio-optical data streams (from both the FLNTU and the F3WB) were extracted from the WETLabs DH4 data handler. Hourly burst samples were binned and the mean, median and standard deviation values computed. The hourly time series is shown in Figure 2. The radiometer data files do not have absolute time metrics within the data files and thus frame counting statistics were used to bin data. This approach was sufficient until February 2017, after which the frame counting was more erratic. The remaining data were processed by hand to correct for uneven sampling within and between burst samples. Automated time merging is currently being implemented and the data files will be updated as available.

Consistent with the real-time data, the turbidity sensor fouled in October 2016 demonstrating characteristics of complete biofilm coverage. In mid-March signatures consistent with structural biofouling were observed with mean values below the saturation limit, suggesting that some of the biofilm had decayed over the winter. Similarly, the chlorophyll fluorometer of the FLNTU displayed biofouling at the end of October, with peak values in November and then decreases until March with strong structural fouling in evidence until the recovery.

Surprisingly, the FL3-WB did not display fouling until the end of May 2017, resulting in nearly an entire year of observations. The wiper on the F3WB is very different from that on the FLNTU (Figure 3) and this deployment suggests that it may be superior for long term deployments.

The FL3-WB Channel 2 data match the FLNTU chlorophyll fluorometer data very closely from July-October 2016 (Figure 2). Therefore the long gap in the FLNTU chlorophyll record, starting in October 2016, is effectively filled by the FL3-WB data. In this report, data from the FL3-WB are shown only in Figures 2 and 4; in later figures only the FLNTU data is shown, so the time periods (during late 2016 and the first half of 2017) when FL3_WB are available nonetheless appear as gaps. For future reporting the goal is to present a merged record in which gaps are minimized.

Downwelling irradiance provided hourly observations for nearly 12 months, while the radiance sensor biofouled completely by October. The latter lacks a biofouling shutter and even though the sensor is deployed face down (to measure upward radiance), the biofouling was substantial. The replication between the FLNTU chlorophyll fluorometer and the 470 nm excitation channel on the FL3-WB is quite robust for the first three months (Figure 4A). These two sensors were independently calibrated in two separate calibration experiments separated by months. This speaks to the robust and painstaking precision in the factory instrument design and characterization, as well as the robust and precise laboratory calibration process.

The three FL3-WB channels are all calibrated to the same *Thalassiosira pseudonana* culture dilution series. Thus if the in situ phytoplankton community was comprised of that species, all three time series would be the same. However, the different pigmentation amongst

phytoplankton taxa results in different relative magnitudes as the composition evolves with time (Figure 4B). The fluorescence ratios (e.g., 470:435 and 532:435, Figure 4C and D) capture the differences in fluorescence efficiency by scaling out variations in biomass. The fluorescence excited at 435 nm is dominated by chlorophyll a. Late summer low biomass conditions display fluorescence ratios characteristic of dinoflagellates. Fall and spring blooms are dominated by diatom-like ratios. Winter months are dominated by cyanobacteria.

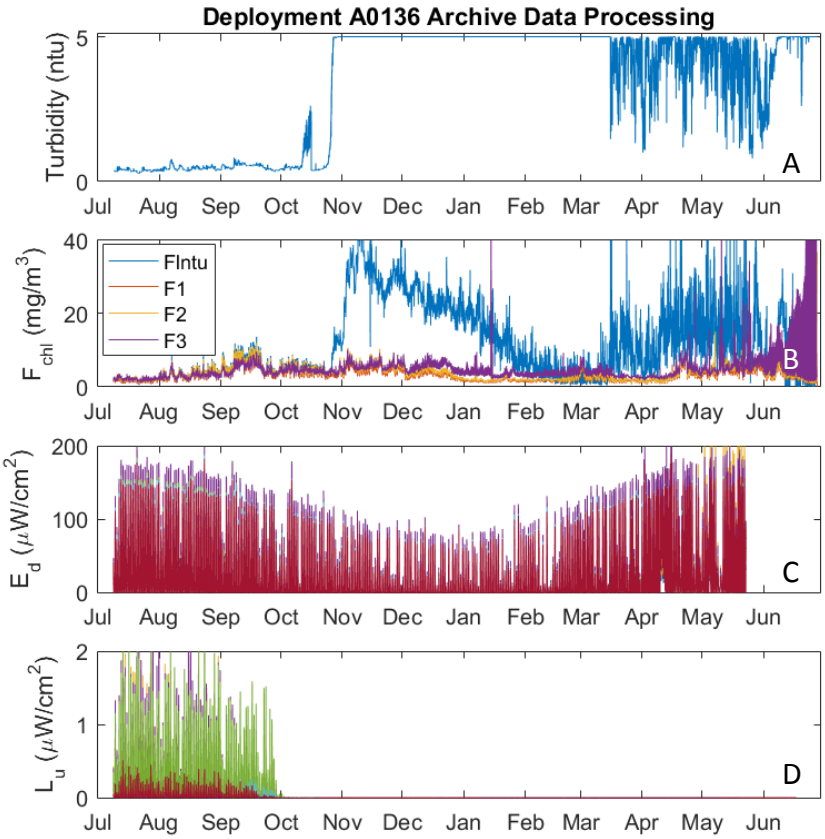

Figure 2. Hourly time series of processed internally-recorded data from deployment A0136 (July 2016 to June 2017) for (A) turbidity, (B) calibrated chlorophyll fluorescence from the FLNTU and FL3-WB sensors, (C) downwelling irradiance, (D) upwelling radiance. In C and D, different colors indicate 7 different wavelengths.

Figure 3. Wiper designs for the WETLabs ECO FLNTU (left) and the ECO Triplet F3WB (right).

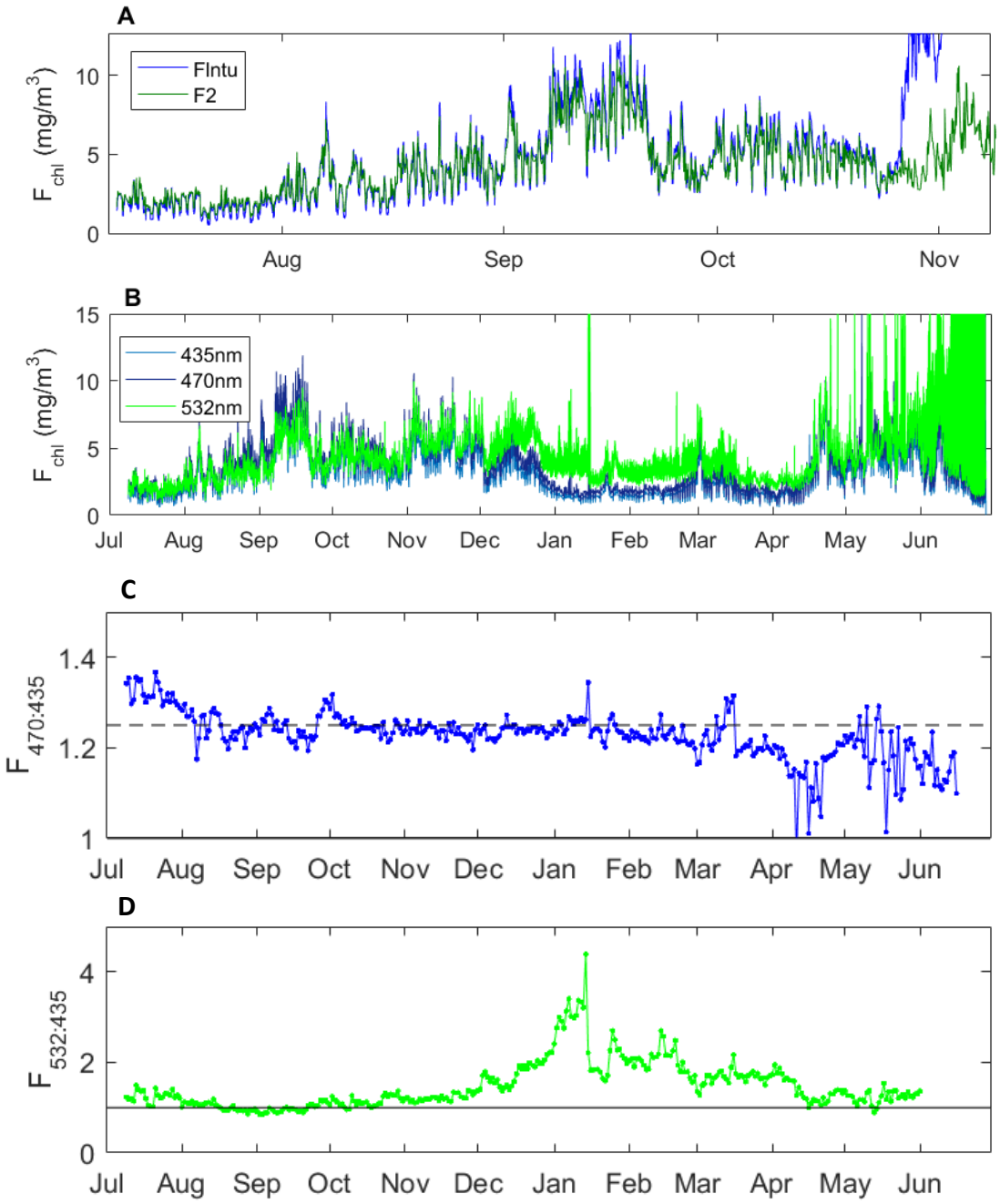

Figure 4. Deployment A0136 (July 2016 to June 2017) hourly observations of calibrated chlorophyll fluorescence measured with **A**. the 470 nm excitation channel of the FLNTU (blue) and the FL3-WB (green) for the first 4 months of the deployment (July to early November 2016), and **B**. all excitation channels of the FL3-WB for the entire deployment. Daily observations, for the entire deployment, of the FL3-WB fluorescence ratios, **C**. 470nm:435nm and **D**. 532nm:435nm.

Complete time series since 2005

Raw hourly data (Figure 5) span deployments A0115 through the initial month of A0137, from December 2005 through July 2017. Turbidity, and sometimes chlorophyll fluorescence, values are typically biofouled by the end of each 6 month deployment.

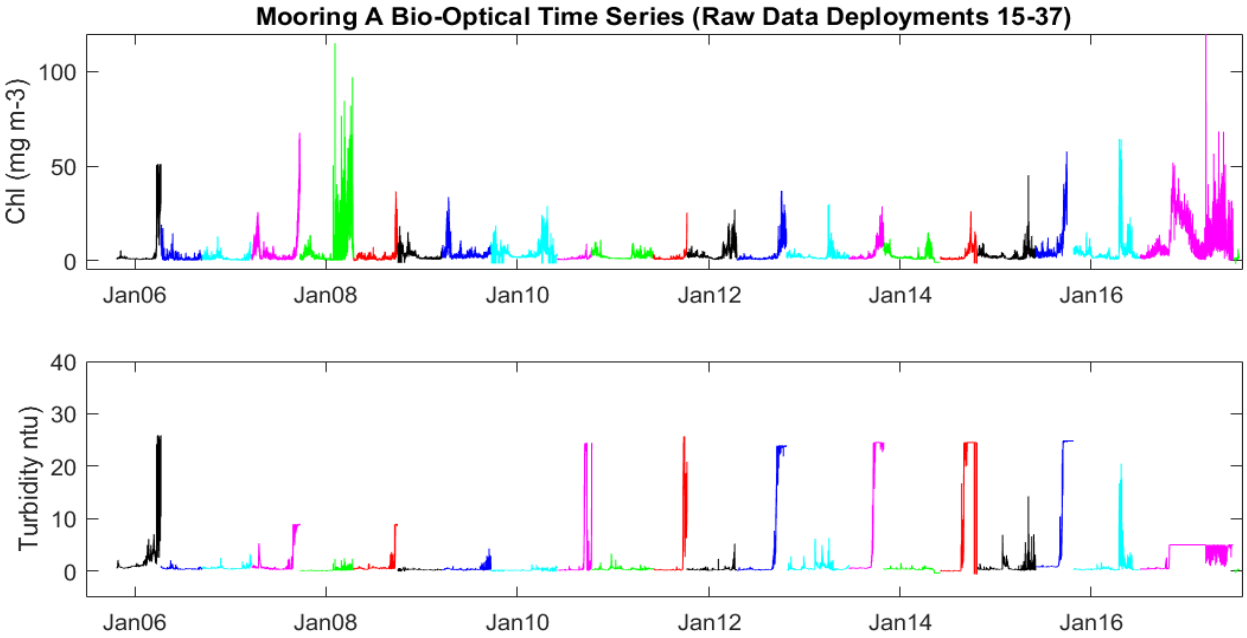

Figure 5. Uncorrected hourly observations of (*top panel*) calibrated chlorophyll fluorescence and (*bottom panel*) turbidity from the FLNTU. Observations color-coded by deployment.

The correction scheme for the hourly chlorophyll fluorescence and turbidity observations follow the sequence from raw hourly observations (Figure 6A and 6B):

1. Offset correction (differences in calibration between deployments, automated correction, Figure 6C and 6D);
2. Biofouling identification (biofilm for which there is a steady increase in the signature, or structural, which may accompany biofilm but is manifested as extremely noisy hourly observations with sustained first difference values in excess of 2 standard deviations; these are manually identified and flagged; Figure 6E and 6F);
3. Non-photochemical quenching flag for daylight hours (1 hour after dawn to 1 hour before sunset, computed from local seasonally varying day length, automated flagging; Fig. 6G);
4. Single value offset removal for isolated data points that exceed 100% coefficient of variation and an absolute value of 15 mg/m^3 (automated flagging and removal);
5. Removal of values more negative than the minimum detection limit (MDL), and flagging of values within the MDL of zero (Figure 6I and 6J).

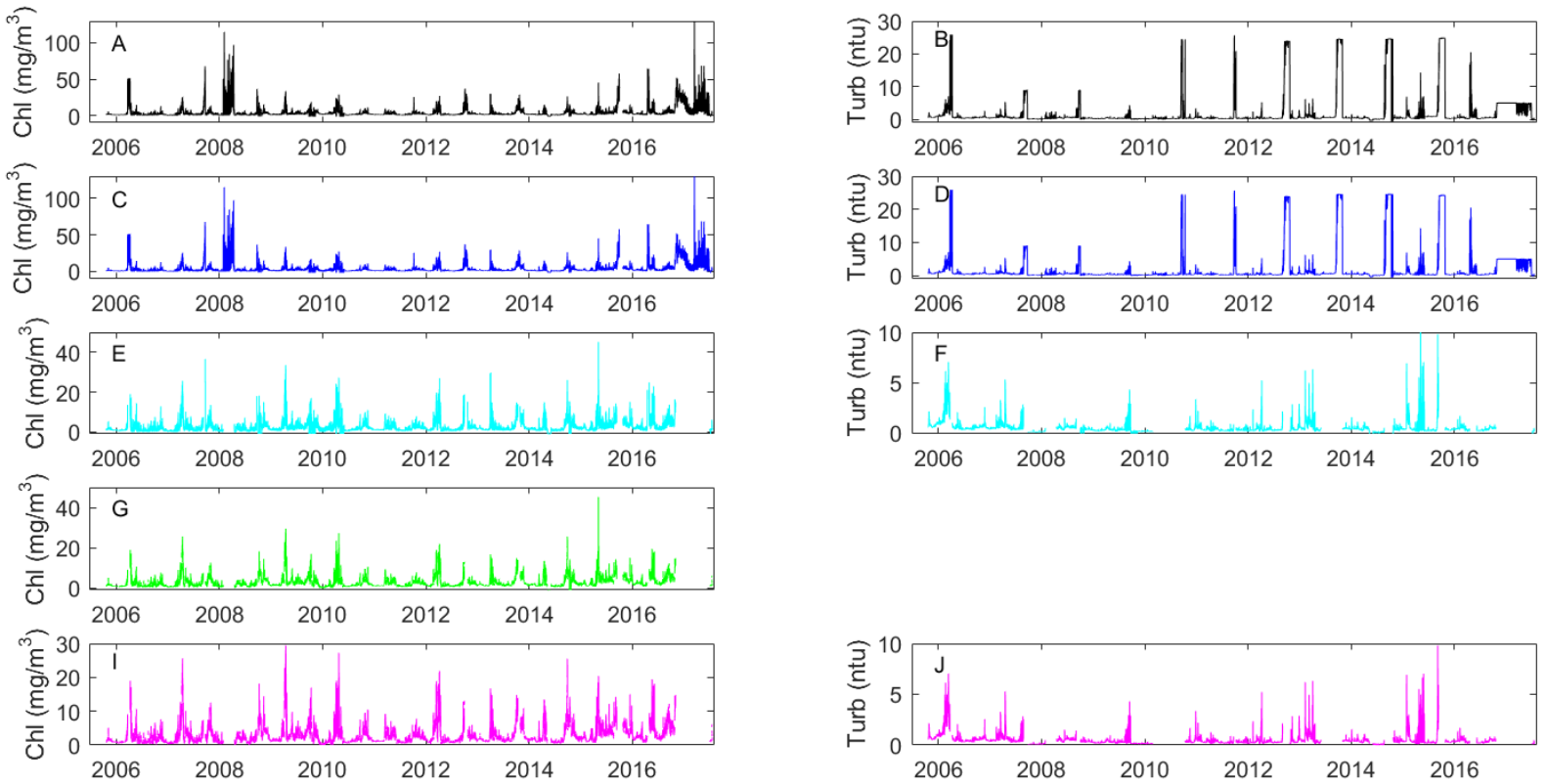

Figure 6. Hourly time series observations of calibrated chlorophyll fluorescence (*left panels*) and turbidity (*right panels*) displaying the impact of flagging and correction or removal: (**A and B**) raw observations; **(C and D)** offset corrections; (**E and F**) biofouling-corrected; (**G**) non-photochemical quenching of fluorescence (there is no **H**); (**I and J**) SVOs (and values less than -1*MDL) removed.

There are currently over one hundred thousand hourly observations of calibrated chlorophyll fluorescence and turbidity from the WETLabs ECO FLNTU (Table 1). Approximately 10% and 24% of them are impacted by biofouling, respectively. As expected, nearly half of the chlorophyll fluorescence observations are impacted by non-photochemical quenching.

Table 1. Number of raw and flagged observations from the WETLabs ECO FLNTU and the resultant time series mean and standard deviation.

	Chlorophyll Fluorescence (mg/m^3)				Turbidity (NTU)		
Statistic	Raw	Biofouled	NPQ	SOV/MDL	Raw	Biofouled	MDL
Number	102,033	10,941	46,641	302	102,633	24,255	1,317
Mean	4.11	2.62	2.75	2.78	1.94	0.45	0.46
Std dev	6.42	2.74	2.77	2.75	5.02	0.51	0.50

The corrected hourly time series of observations of calibrated chlorophyll fluorescence clearly shows two seasonal blooms per year, while the turbidity time series does not display clearly delineated annual cycles (Figure 7). Springtime bloom concentrations peak at approximately 10 mg m^{-3} although can be as high as 20 mg m^{-3}.

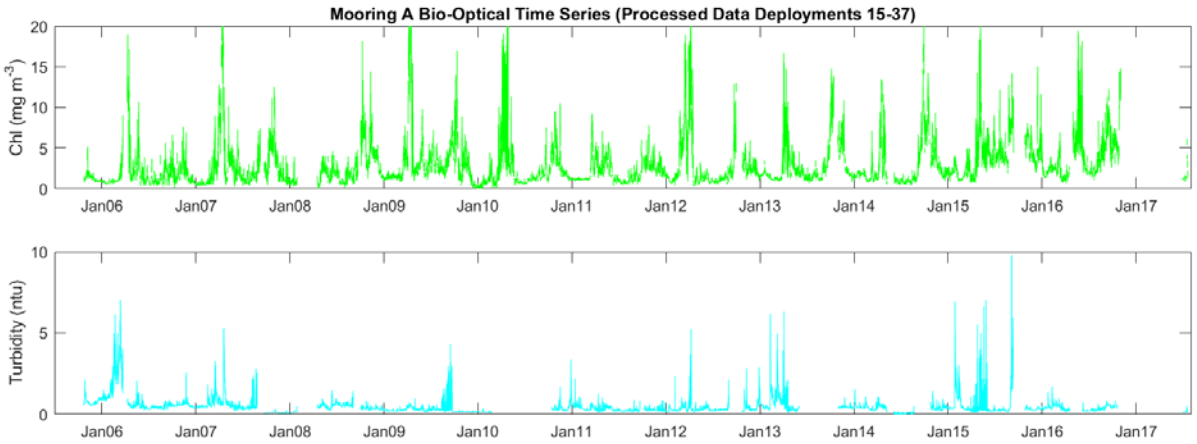

Figure 7. Corrected hourly observations of calibrated chlorophyll fluorescence (*top panel*) and turbidity (*bottom panel*).

There is significant variability in the annual cycle of chlorophyll fluorescence (Figure 8) with the spring bloom peaking as early as March or as late June. The fall bloom appears to be less variable in timing and sometime exceeds the spring bloom in magnitude. The FLNTU observations from late 2016 and the first half of 2017 were severely impacted by biofouling, as demonstrated by the gaps in the record in the 2016 and 2017 frames of Figure 8; redeployment of the mooring each fall is critical for capturing the spring bloom as deployments early in the calendar year are often limited by weather. As noted above, although not presented in Figure 8, the FL3-WB collected good data during these gaps.

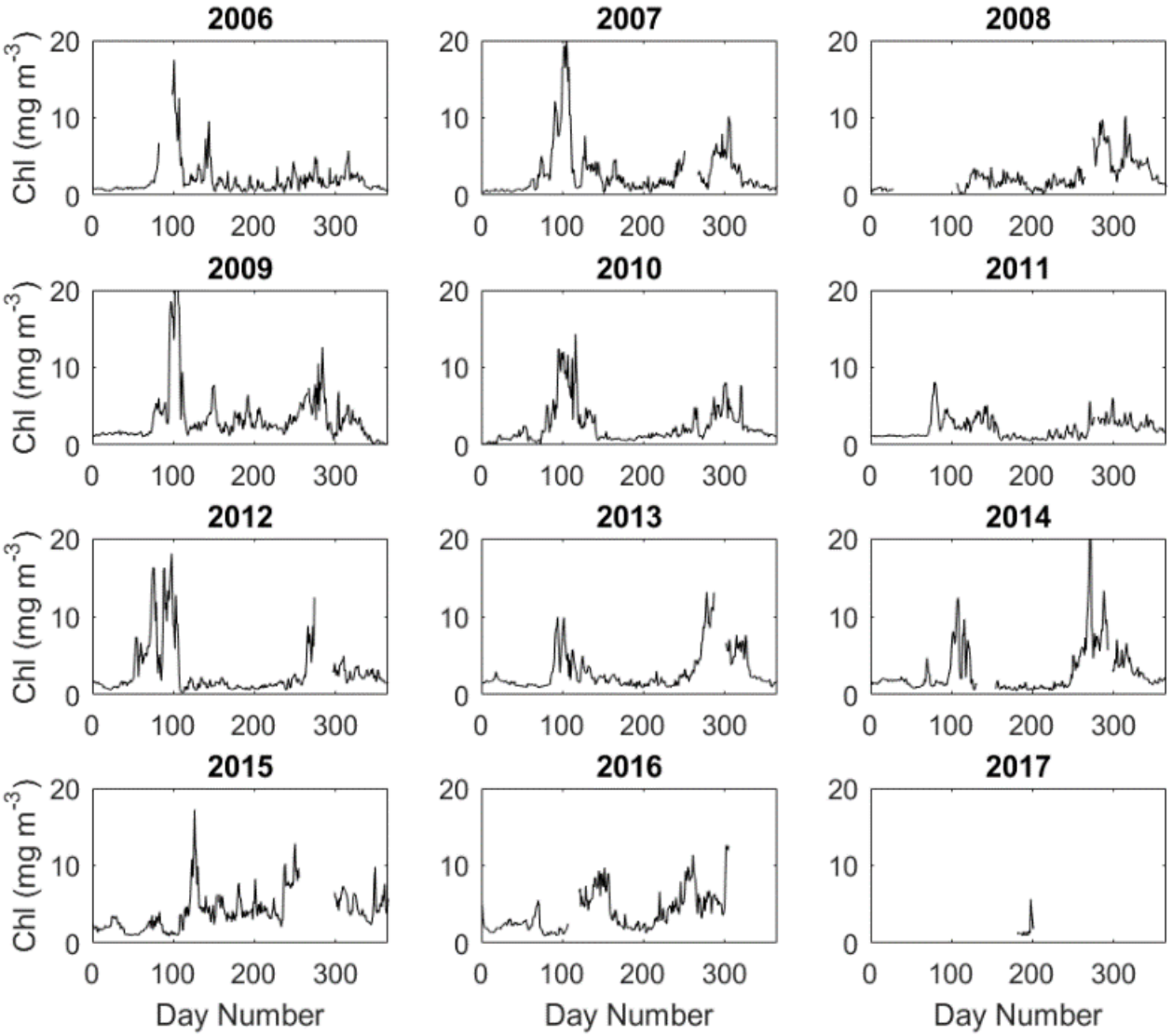

Figure 8. Annual cycle of daily chlorophyll fluorescence for each year of deployment (2005, a partial year, not shown). Data through July 20, 2017 (Day Number 201 of the 2017 frame, at lower right) are included in this report.

The magnitude and seasonal patterns of the daily chlorophyll compares favorably with the time series of monthly satellite derived chlorophyll obtained from MODIS (**Mod**erate resolution **I**maging **S**pectroradiometer) using GIOVANNI (**G**oddard Earth Sciences Data and Information Services Center **I**nteractive **O**nline **V**isualization and **An**alysis **I**nfrastructure) for the box bounded by 70.6 to 70.5W and 42.5 to 42.55 N (Figure 9).

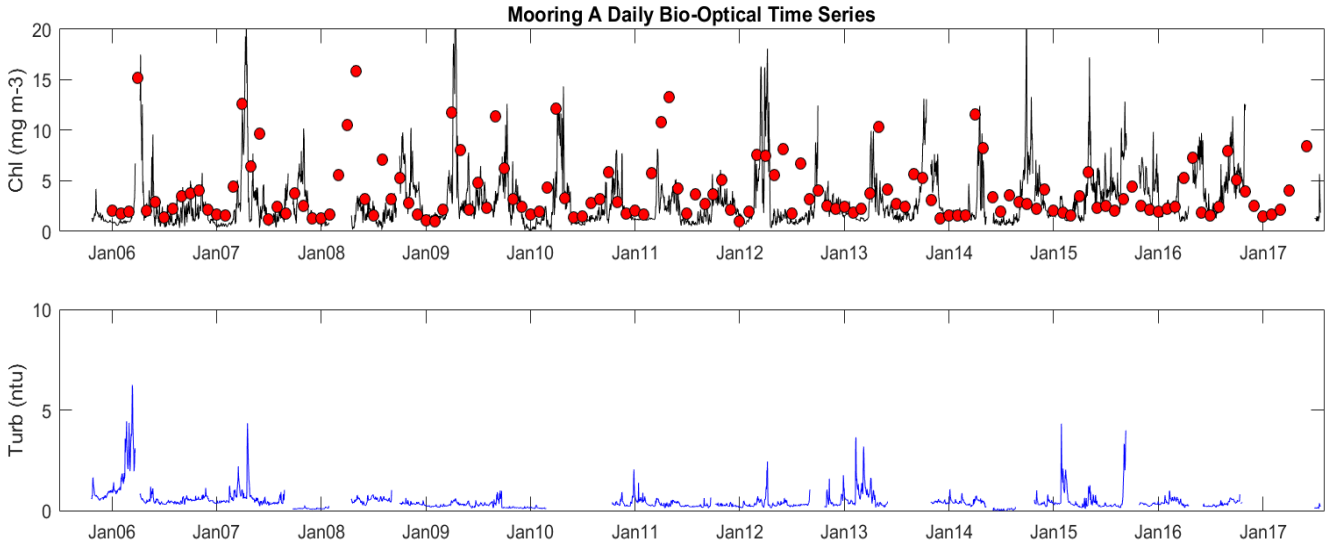

Figure 9. Time series observations of (*top panel*) daily calibrated chlorophyll fluorescence (black line) and monthly MODIS ocean color-derived chlorophyll (red symbols, MODIS data) and (*bottom panel*) turbidity for Buoy A01.

The daily average chlorophyll values for the years 2005 through 2017 show clear spring and fall blooms in chlorophyll (Figure 10A, 10B). The daily turbidity values are much more variable and thus their average level is lower (Figure 10C, 10D), with increases observed in winter and spring, and generally lowest values in the summer and fall other than a peak in September.

An analytic function consisting of three Gaussian functions (for the two spring and single fall blooms) and a background level of chlorophyll fit to the daily observations indicates that the magnitudes of the three blooms are approximately 7.2, 2.1 and 4.3 mg chl m^{-3}, respectively, with a background of approximately 1.25 mg chl m^{-3}. The timing of the bloom peaks are April 12, May 16 and October 16 with bloom durations of approximately 8, 12, and 23 days, respectively. There is some evidence of a second fall bloom that occurs in mid-Nov but is of much lower amplitude.

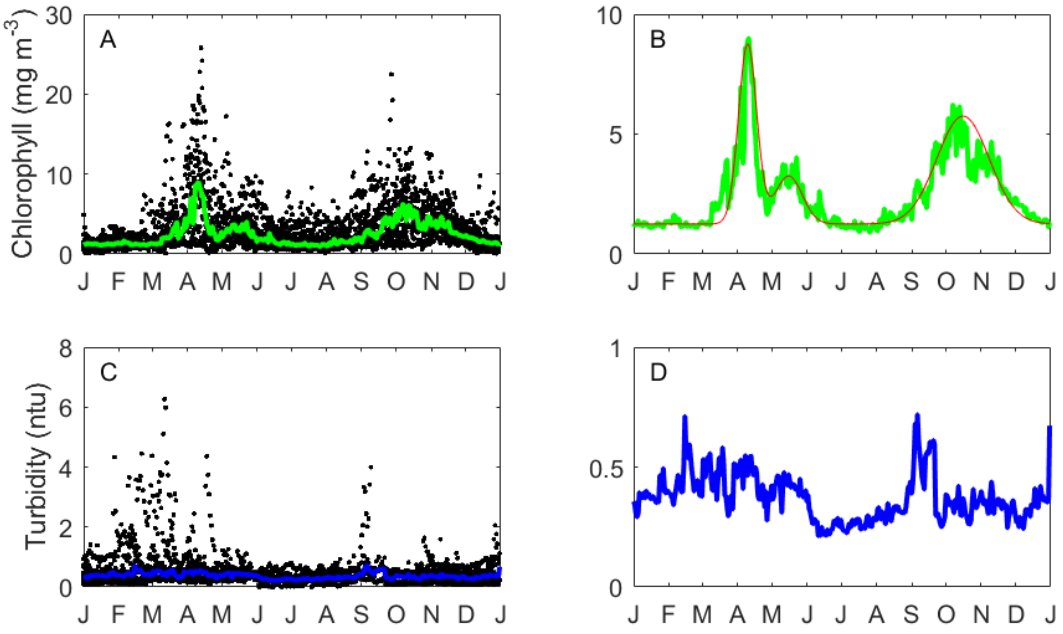

Figure 10. Daily observations, all 12 years of sampling superposed. Chlorophyll fluorescence (*top panels*) and turbidity (*bottom panels*) shown by black dots in A and C. Daily averaged values shown by green and blue symbols for chlorophyll and turbidity, respectively. Expanded scales for the daily averaged values in B and D. The three-Gaussian model of seasonal chlorophyll given by red line in B.

Conclusions

The highlights for the year-long deployment A0136 are:

- One year deployments that begin in the summer result in significant bio-fouling by the end of the calendar year, and loss of the spring and summer data.
- The WETLabs ECO triplet anti-biofouling shutter design (on the FL3-WB) is superior compared to the shutter on the FLNTU for long deployments.
- Redundant chlorophyll fluorometers provide validation of replicated signal.
- Multichannel fluorometers reveal successional patterns in phytoplankton community structure.
- Above water irradiance sensors remaing clean of fouling or degradation over the year deployment and are useful for identifying time intervals of NPQ in chlorophyll fluorescence.
- In-water upwelling radiance sensors that lack antibiofouling shutters become biofouled within 3 months.

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Appendix A. Data file formats.

Table A1. Format of the hourly observational data file for chlorophyll fluorescence data arrays. Date/time information is in the Eastern Standard Time (EST) time zone.

Column	ID	Value/Range	Comment
1	Year	2005-2016	
2	Month	1-12	
3	Day	0-31	
4	Hour	0-25	
5	Minute	0-60	
6	Second	0-60	
7	Date.Time	732607 - 736575	Matlab format
8	Raw Fchl	-1.63 - 115.04	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	NaN	Values removed
16	Flag_SVO	0, 1	Single value outlier
17	Fchl_corr_SVO	NaN	Values removed
18	Flag_MDL1	0, 1	<-Minimum level detection
19	Flag_MDL2	0, 1	-MDL to 0
20	Flag_MDL3	0, 1	0 to +MDL
21	Fchl_corr	Value or NaN	Cumulative removal/correction
22	Deployment	15 - 37	Deployment number

Table A2. Format of the hourly observational data file for Turbidity. Date/time information is in the Eastern Standard Time (EST) time zone.

Column	ID	Value/Range	Comment
1	Year	2005-2016	
2	Month	1-12	
3	Day	0-31	
4	Hour	0-25	
5	Minute	0-60	
6	Second	0-60	
7	Date.Time	732607 - 736575	Matlab format
8	Raw Turbidity	-0.60 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	<-Minimum level detection
17	Flag_MDL2	0, 1	-MDL to 0
18	Flag_MDL3	0, 1	0 to +MDL
19	Turb_corr	Value or NaN	Cumulative removal/correction
20	Deployment	15 - 36	Deployment number

Table A3. Format of the hourly observational data file for downwelling irradiance and upwelling radiance. Date/time information is in the Eastern Standard Time (EST) time zone.

Column	ID	Value/Range	Comment
1	Year	2005-2016	
2	Month	1-12	
3	Day	0-31	
4	Hour	0-25	
5	Minute	0-60	
6	Second	0-60	
7	Date.Time	732607 - 736575	Matlab format
8-14	Raw Ed(7)	-0.60 25.95	
15	Flag_Offset	0, 1	
16-22	Ed(7)_corr_offset		Corrected for 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	<-Minimum level detection
33	Flag_MDL2	0, 1	-MDL to 0
34	Flag_MDL3	0, 1	0 to +MDL
35-41	Ed(7)_final	NaN	Cumulative removal/correction
42	Deployment	15 - 36	Deployment number

Table A4. Format of the daily observational data file for chlorophyll fluorescence. Date/time information is in the Eastern Standard Time (EST) time zone.

Column	ID	Value/Range	Comment
1	Year	2005 to 2017	
2	Month	1-12	
3	Day	0-31	
4	Date	732607 to 736575	Matlab format
5	Mean Fchl	-0.01 to 25.79	Daily mean chlorophyll
6	Median Fchl	-0.01 to 25.45	Daily median chlorophyll
7	Stdev Fchl	0.00 to 5.86	Daily standard deviation
8	N	0 to 24	N^{o} hourly obs in daily value
9	Deployment	15 to 36	Deployment number

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