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Southern Ocean Time Series (SOTS) Quality Assessment and Control Report PAR Instruments

Version 2.0 - December 2020

Photosynthetically Available Radiation Records 2009-2019

Peter Jansen, Thomas W. Trull, Christina Schallenberg, James Harley

IMOS
Integrated Marine Observing System

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Executive summary

The Southern Ocean Time Series (SOTS) Observatory located near 141°E and 47°S provides high temporal resolution observations in Subantarctic waters. It is focused on the Subantarctic Zone because waters formed at the surface in this region by deep wintertime convection slide under warmer subtropical and tropical waters, carrying CO_2 and heat into the deep ocean, where it is out of contact with the atmosphere. This process also supplies oxygen for deep ocean ecosystems, and exports nutrients that fuel ~70% of global ocean primary production. Local biological production also impacts carbon cycling and the SOTS moorings measure several variables important to these processes, including photosynthetically available radiation (PAR).

This report describes the quality control procedures applied to PAR data collected from the SOTS moorings between 2009 and 2019.The quality-controlled datasets are publicly available via the IMOS Data Portal. This report should be consulted when using the data.

1 Introduction

The Southern Ocean Time Series (SOTS) Observatory provides high temporal resolution observations in Subantarctic waters. Observations are broad and include measurements of physical, chemical and biogeochemical parameters from multiple deep-water moorings in the Subantarctic Zone southwest of Tasmania (Figure 1). The emphasis is on seasonal and inter-annual variations of lower atmosphere and upper ocean properties and their influence on exchange with the deep ocean. The continuous time-series information allows the study of ocean physics and chemistry, climate change, carbon cycling and biogeochemical controls on marine productivity. These moorings provide cost-effective observations and overcome the infrequent availability of ships in the region. The Southern Ocean Time Series is an Australian contribution to the international OceanSITES global network of time series observatories (www.OceanSITES.org) and is one of the few comprehensive Southern Ocean sites globally. More information on the SOTS Sub-Facility is available on-line at http://www.imos.org.au/.

The Southern Ocean (south of 30°S) is responsible for ~40% of the total global ocean uptake of human-induced CO_2 emissions, and 75% of the additional heat that these emissions have trapped on Earth. The Southern Ocean Time Series site is focused on the Subantarctic Zone because waters formed at the surface in this region, the Subantarctic mode and Antarctic Intermediate waters, slide under warmer subtropical and tropical waters and carry this CO_2 and heat into the deep ocean, out of contact with the atmosphere. This process also supplies oxygen for deep ocean ecosystems, and exports nutrients that fuel ~70% of global ocean primary production. The Subantarctic Zone and these processes are expected to change with global warming but the potential impacts of these changes are not yet known.

The Southern Ocean Time Series site southwest of Tasmania is comprised of a number of elements including a deep ocean sediment trap mooring (SAZ), a surface biogeochemistry mooring (Pulse) and an air-sea flux mooring (SOFS). Located in the sub-Antarctic Zone near 141°E, 47°S, the site is particularly vulnerable to the extreme weather events that typify the area including very large waves, strong currents and severe storms, presenting significant technical and engineering challenges.

SOTS (red star in Figure 1) is located in a low current region, north of the Subantarctic Front (SAF) that marks the northern edge of the Antarctic Circumpolar Current. SOTS is located in deep waters (>4500 m) west of the Tasman Rise (the shallow region south of Tasmania; with waters less than 2000m deep, shown in blue). The SOTS site exhibits oceanographic properties representative of the Australian sector of the sub-Antarctic Zone (from ~90 to 145 °E; Trull et al., 2001). Waters flowing southward in the East Australian Current reach this region by transiting through channels in the Tasman Rise (Herraiz-Borreguero et al., 2011).

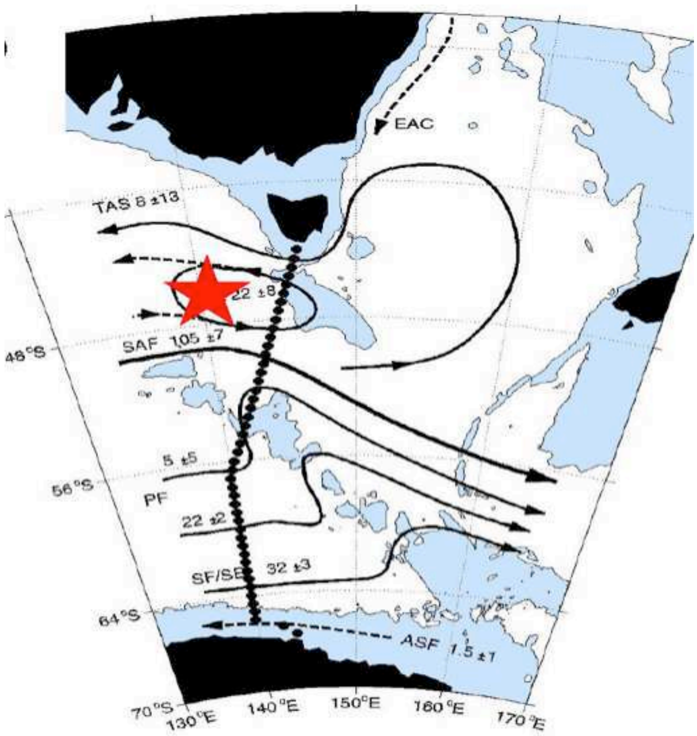


Figure 1 Location of the SOTS observatory; Figure adapted from Herraiz-Borreguero et al., 2011

2 Moorings Description

The Southern Ocean Time Series moorings are the Pulse biogeochemistry mooring, the Sub-Antarctic Zone (SAZ) sediment trap mooring, and the Southern Ocean Flux Station (SOFS).

The Pulse biogeochemistry mooring is used to measure upper ocean carbon cycle and phytoplankton productivity processes. Measured parameters include temperature, salinity, dissolved oxygen, total dissolved gases, nitrate, chlorophyll fluorescence and optical particulate backscatter. This mooring also collects water samples for measurements of dissolved carbon and nutrients, and phytoplankton microscopic identification.

The SAZ sediment trap mooring collects sinking particles to quantify carbon fluxes, and provides current meter measurements and a deep ocean CTD to measure heat contents below the depth of Argo profiling float measurements.

The SOFS meteorological tower mooring has dual sets of incoming solar radiometers, temperature and humidity sensors, precipitation gauges and sonic anemometers, and a pCO_2 sensor provided by NOAA. Surface photosynthetically active radiation (PAR) is also measured to help assess light available for phytoplankton production.

All three moorings are anchored to the ocean floor ~4.5 kilometres below the surface. The SOFS and Pulse moorings are s-tether designs that are longer than this, and correspondingly their surface floats move in large ‘watch circles’. In contrast, the SAZ mooring is a stiff subsurface mooring with all components more than 700m below the surface. The moorings record hourly sensor observations until they are swapped with a duplicate mooring the following year. In the 2016-17 year, the SOFS and Pulse capabilities were combined into a single prototype mooring known as FluxPulse-1.

Surface data collected from Pulse and SOFS are relayed back by satellite. The sub-surface data are stored and downloaded when the moorings are retrieved (approximately a year later). All data are available via the Australian Ocean Data Network (AODN) Portal.

3 Summary of Instruments

A total of 11 different instruments for measuring PAR were deployed at SOTS between 2009 and 2019. These instruments were deployed on two different mooring designs, at varying depths ranging from the surface to a depth of 50m (Refer to table 1 for the deployment depth of each sensor). All instruments were mounted facing upwards.

The PAR sensors deployed at SOTS can be divided into two main functional categories: cosine and spherical. Cosine sensors measure PAR as a downwelling vector quantity, whereas spherical sensors measure PAR as a scalar quantity.

Cosine sensors receive downwelling light through a flat surface and thus underestimate PAR as experienced by phytoplankton, as they are incapable of receiving upwelling light. However, they work well for estimating the downward attenuation of PAR. These sensors use a material that minimizes reflective losses and diffuses light to provide an approximately cosine response to incident angle, as required to estimate the downwelling component of the radiation. As these sensors receive light through a flat surface, they can be wiped to prevent biofouling. Of the cosine sensors deployed at SOTS, only the WET Labs cosine sensors had a wiper attached.

Spherical sensors use a spherical surface to diffuse incoming light before it reaches the sensor. This is intended to provide a more accurate representation of the way in which a cell in the water would receive light. This structure means that sensors mounted at or above the surface may receive light reflecting from the ocean surface. Additionally, spherical sensors are more susceptible to biofouling as the spherical surface cannot be wiped while the sensor is deployed (Kirk 1994).

Table 1. Instrument deployment details for cosine sensors

PRODUCER	MODEL	SERIAL NO.	DEPLOYMENTS AND DEPTH
Alec Electronics	DEFI-L	082V023	Pulse-10-2013 (50m) Pulse-11-2015 (50m)
WET Labs	ECO-PAR	134	Pulse-8-2011 (31.1m) Pulse-10-2013 (28m) Pulse-11-2015 (28m)
WET Labs	ECO-PAR	135	Pulse-6-2009 (37.5m) Pulse-7-2010 (31.1m) Pulse-9-2013 (38.5m)
Wet Labs	ECO_PARS	419	SOFS-7-2018 (30m) SOFS-7.5-2018 (30m)
LiCor	LI-190	Q47470	SOFS-4-2013 (Surface - in air) SOFS-5-2015 (Surface - in air) SPFS-6-2017 (Surface - in air) SOFS-7-2018 (Surface - in air) SOFS-7.5-2018 (Surface - in air)
LiCor	LI-190SA	Q40966	SOFS-1-2010 (Surface - in air) SOFS-2-2011 (Surface - in air) SOFS-3-2012 (Surface - in air) FluxPulse-1-2016 (Surface - in air)

Table 2. Instrument deployment details for spherical sensors

PRODUCER	MODEL	SERIAL NO.	DEPLOYMENTS AND DEPTH
Alec Electronics	MDS-MKV/L	201318	SOFS-1-2010 (40m) SOFS-2-2011 (40m) SOFS-4-2013 (20m) SOFS-5-2015 (20m)
Alec Electronics	MDS-MKV/L	201319	SOFS-2-2011 (10m) SOFS-4-2013 (40m) SOFS-5-2015 (40m)
Alec Electronics	MDS-MKV/L	200341	Pulse-6-2009 (Surface*) Pulse-7-2010 (Surface) Pulse-8-2011 (50m) Pulse-10-2013 (Surface)
Alec Electronics	MDS-MKV/L	200664	Pulse-6-2009 (27m) Pulse-7-2010 (50m) Pulse-8-2011 (27m)
Alec Electronics	MDS-MKV/L	200665	Pulse-6-2009 (50m) Pulse-7-2010 (27m) Pulse-8-2011 (Surface) Pulse-10-2013 (50m) Pulse-11-2015 (20m)

*surface instruments were in air

4 Summary of Instrument Handling and Data Processing

All Alec Electronics sensors logged to their internal memories. LiCor sensors were logged by a CR1000 data logger. The WETLabs sensors were logged both internally and by an SBE16plusV2. Data obtained from periods when the instruments were out of the water were given a flag value of 6 before initiation of the QC tests applied here, with these flags carried through to the final data products. See Table 4 for flag assignments.

Sensor calibrations are based on different relationships between logged counts and PAR for each sensor type. All PAR data are reported as photon fluxes in units of µmol $m^{-2}s^{-1}$.

The Wet Labs sensors are logarithmic sensors, with counts converted to PAR using the following formula:

$$\boldsymbol{PAR = Im \times 10^{\frac{counts - a0}{a1}}}$$

(Eqn 1.)

Im is a water immersion correction (=1 when deployed in air), a0 corrects any offset from the reference count value for PAR =1, and a1 represents the sensor's sensitivity.

The LiCor and Alec Electronics sensors are proportional sensors, with counts converted to PAR using the following formula:

$$\boldsymbol{PAR = A + B \times counts}$$

(Eqn 2.)

Where A is an offset correction and B describes the sensor's sensitivity.

More detail on the specifics of these calibrations can be found in Appendix B.

5 QC Specifics

The hierarchy of tests recommended by Integrated Ocean Observing System (IOOS) for Quality Assurance of Real-Time Oceanographic Data (QARTOD; https://ioos.noaa.gov/project/QARTOD) was adapted for PAR data quality control. Some of the tests were not applicable to the PAR data and were not conducted, as described in section 5.4 and shown in Table 3. Each test was applied to all data points, including those that had been flagged as fail (flag=4) or suspect (flag=3) in previous tests (see Table 4 for flag nomenclature), and the highest flag from all tests is retained as the overall flag.

5.1 QC tests and flags

Table 3. QC tests recommended by QARTOD for real-time quality assurance for coastal and oceanic ocean optics observations.

TEST GROUP	TEST NO.	TEST NAME	CONDUCTED
Group 1	Test 1	Timing/Gap Test	Yes
Required	Test 2	Syntax Test	Yes
	Test 3	Location Test	Yes
	Test 4	Gross Range Test	Yes
	Test 5	Decreasing Radiance, Irradiance, and PAR Test	N/A
Group 2	Test 6	Photic Zone Limit for Radiance, Irradiance, and PAR Test	N/A
Strongly Recommended	Test 7	Climatology Test	Yes
	Test 8	Spike Test	No
	Test 9	Rate of Change Test	No
	Test 10	Flat Line Test	Yes
Group 3	Test 11	Multivariate Test	No
Suggested	Test 12	Attenuated Signal Test	No
	Test 13	Neighbour Test	Yes

Table 4. Flags used in PAR quality control

The QC flags are provided in the on-line netcdf files and follow the Argo Table 2A Flag convention (equivalent to IMOS Standard Flag, OCEANSITES, and IODE flag conventions) and are as follows:

N	MEANING
0	no QC was performed
1	good data
2	probably good
3	bad data that are potentially correctable
4	bad data
5	value changed
6	not deployed
7	not used
8	interpolated value
9	missing value

5.2 Applied tests

Test 1. Timing/Gap Test:

The timing/gap test checks that all measurements were made at the correct time intervals. The only problem found was that for the in-air sensors on SOFS-1, 2, 3, 4, and 5, on some days only 23 hourly values were recorded (instead of the expected 24). This was considered unlikely to affect data quality and no flags were applied (see Discussion section for note on calculation of daily (24 hour) averages from these data). No other problems were found and therefore no flags were applied. Note that daily means calculated for days with only 23 hourly observations should be based on averaging the PAR observations by the recored length (23) and not assume 24 hours.

Test 2. Syntax Test:

The syntax test ensures that all measurements were made in the correct data format. No problems were found and therefore no flags were applied.

Test 3. Location Test:

The location test is used to check that all measurements were taken at the correct location and at the correct depth. No problems were found and therefore no flags were applied.

Test 4. Gross Range Test:

The gross range test checks whether the data are within a reasonable range of values. All data with a value less than -1.7 or higher than 10,000 µmol m^{-2} s^{-1} were flagged as a fail (flag = 4), and valuse above 4500 µmol m^{-2} s^{-1} were flagged as suspect (flag = 3).A lower bound of -1.7 was chosen because the lowest intercept (A) value for the proportional sensor is approximately -1.68. In principal the logarithmic sensors can never produce values less than 0. Therefore, this A value is the lowest possible value a sensor in this sensor set could return when 0 counts are obtained. **As the lower bound for this test is specific for this sensor set, future users of this quality control process will need to set their own lower bound**.

Test 7. Climatology Test:

The climatology test functions similarly to the gross range test, but threshold values change seasonally. To create bounds for this test, estimates of maximum expected PAR at each depth were created from modelled incident solar irradiance at the top of the atmosphere, propagated to the ocean surface assuming no losses and propagated onward to ocean depth using the clear water value of the diffuse attenuation coefficient (K_d = 0.04). This is a conservative K_d value as seasonal variation is expected. Summer K_d values reaching 0.1 have been measured at the SOTS site from CTD casts, and in winter light hits the water at a lower incident angle, decreasing light below the surface due to reflection at the surface.

The solar irradiance model uses the solar constant value of 1,361 W m^{-2} and then creates a seasonal cycle based on the Earth's orbit and the solar altitude at different times of year. Top of atmosphere incoming solar radiation values (Figure 2) corresponding to each PAR measurement were calculated using the *suncycle.m* Matlab function (see Appendix A). This function calculates the expected clear-sky solar radiation based on latitude, longitude and date.

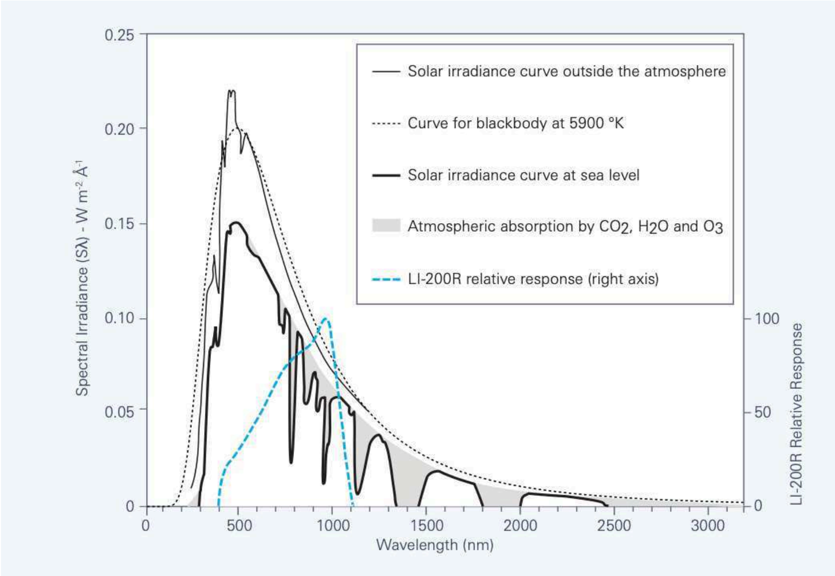


Figure 2 distribution of solar energy

All calculated solar radiation values from suncycle.m were converted from short wave (SW) radiation (300-2000 nm) in units of W m^{-2} to PAR (400-700 nm) in units of µmol m^{-2} s^{-1} using a conversion coefficient of PAR = 2.114 x SW. This conversion is approximate, because it depends on the spectral qualities of the radiation after passing through the atmosphere. The conversion combines two steps: i. estimating the fraction of SW represented by PAR and ii. converting PAR units from energy (W m^{-2}) to photon flux (umol m^{-2} s^{-1}). For step i., the fraction of SW represented by PAR averages 0.46 with a seasonal range of ~4% as estimated by comparing SW and PAR sensors under varying sky conditions in Texas, USA (Britten and Dodd, 1976). For step ii., PAR (in µmol m^{-2} s^{-1}) = ~4.57 x PAR (in W m^{-2}) for combined sun and sky irradiance, with variation of ~9% in this conversion factor across different sky conditions based on measurements in New Zealand (McCree, 1972; his Table II). Together these lead to the conversion factor of 2.114 (4.57 x 0.46) with precision of ~10%.

The downwelling climatological PAR estimated was calculated according to the following formula:

$$\boldsymbol{PAR\ (sensor\ depth\ z) = PAR\ (at\ ocean\ surface)} \times \boldsymbol{e^{-Kd \times depth\ z\ of\ sensor}}$$

(Eqn 3.)

These PAR values represent the amount of down-welling radiation that would theoretically reach the sensors on a sunny, clear-sky day with completely clear water (for K_d = 0.04), and no modulation by the air-sea interface (losses at the interface are typically 2-20% increasing with the angle from the vertical; thus assuming no loss leads to a conservative upper estimate of expected PAR). Spherical geometry sensor values can exceed these values by a factor of 2. Reflections from the sea-surface can further increase radiation for in-air sensors, and focusing of light by waves can affect in-water sensors. To allow for these factors, we set the PAR threshold for this test as 3 times the climatological value, and any sensor values higher than this were assigned a flag value of 3.

This test is less useful during dawn, dusk, and night as light conditions are not well represented by the solar radiation model (e.g. as a result of moonlight, low angle reflections from clouds, or refraction in the atmosphere) and the test begins to flag a large number of values that may be of good quality (an example is shown in Figure 3). Therefore, all data points when the sun altitude was below 10 degrees were deemed unable to be evaluated by the test and were assigned a flag value of 2, and when the sun was 15 degrees below the horizon, radiation values above 15 umol m^{-2} s^{-1} were flagged 4. Figures 4 and 5 show examples of the daily light cycle at the ocean surface (which has similar shape to that of the incoming insolation at the top of the atmosphere) and below the surface (where the daily cycle has a more triangle shape as a result of the surface reflection dependence on the insolation angle). These daily cycles are also strongly modulated by variations in cloudiness.

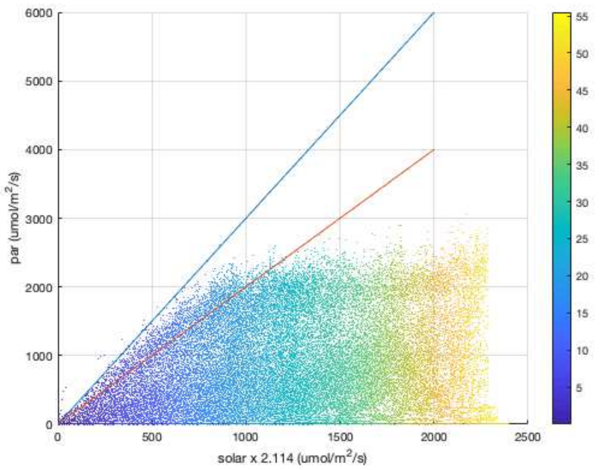


Figure 3 surface spherical sensor example distribution, lines for 2x and 3x incoming radiation, coloured by sun altitude

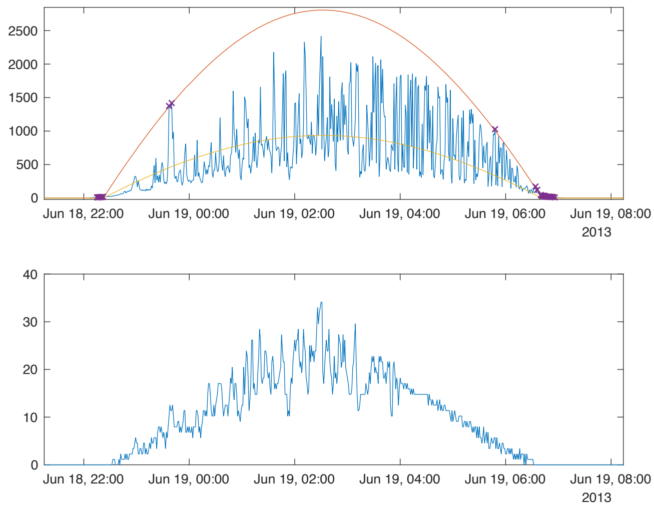


Figure 4 TOP: example surface spherical PAR sensor, lines for solar and 3x solar, BOTTOM: 50m spherical sensor

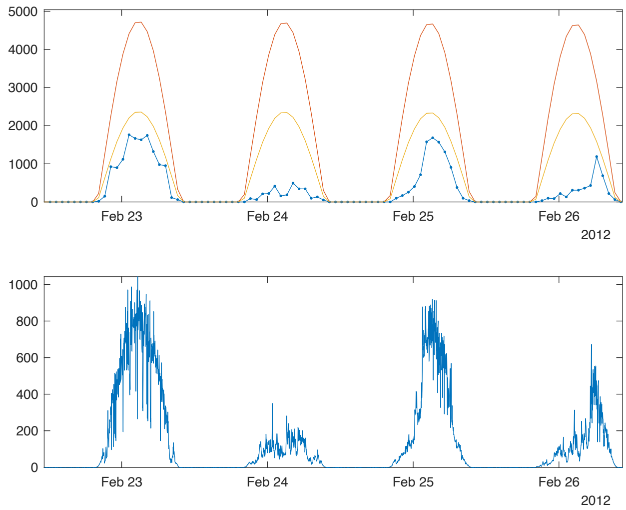


Figure 5 TOP: example surface cosine sensor with solar and 2xsolar, BOTTOM: 10m spherical sensor

Test 10. Flat Line Test:

The flat line test is intended to catch decreasing sensor sensitivity or failure. The flat line test was applied across all sensors. This test was only run on daytime data as all sensors would be expected to flat line somewhat during the night.

The flat line test was implemented using a rolling window of 5 data points. The following formula was applied to each set of data points:

$$|\boldsymbol{maximum\ value} - \boldsymbol{minimum\ value}| = \mathbf{0}$$

(Eqn 4.)

The final data point in any set of 5 points that returned TRUE for equation 5 was assigned a flag of 4. Any points that were unable to be evaluated due to not having enough subsequent points to create a window of 5 points were assigned a flag value of 2.

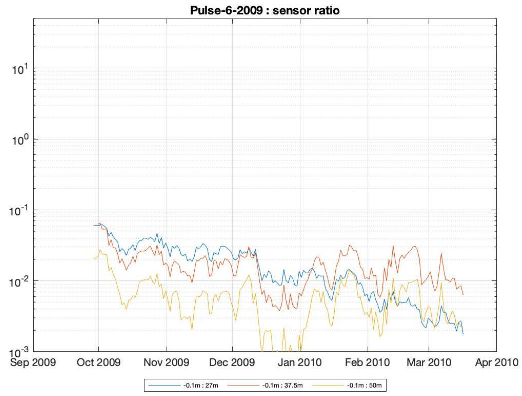
Test 13. Neighbour Test:

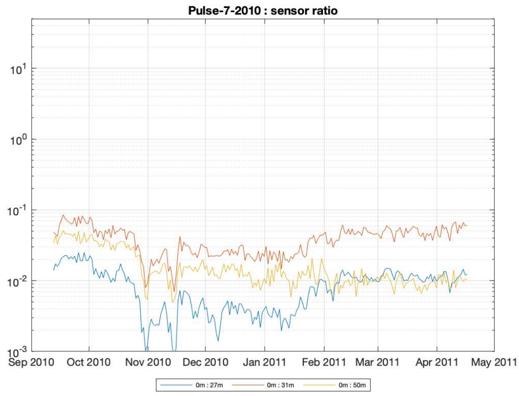
The neighbour test used all PAR sensors deployed on the same mooring and compared their records. The theory is that all sensors should show similar trends with time, with the sensors at greater depths giving a more attenuated signal. The test thus consisted of comparing each sensor to those mounted below and above them on the mooring. Daily means were used so that offsets between sensor clocks would not lead to flagging of data on days with fast passing clouds.

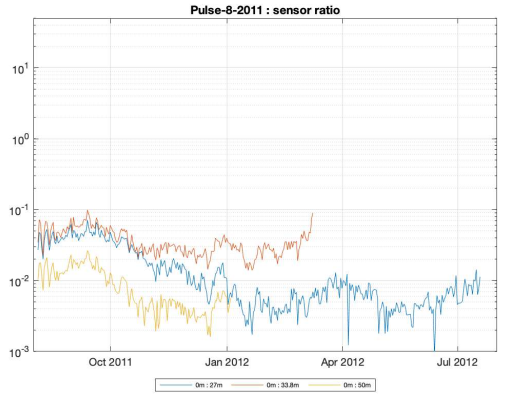
In Version 1.0 of this report, these comparisons were automated, but as noted there this meant that when only two sensors disagreed, e.g. with the shallower sensor having lower PAR than the deeper sensor, it was not possible to know which sensor was in error and thus both were flagged as suspect.

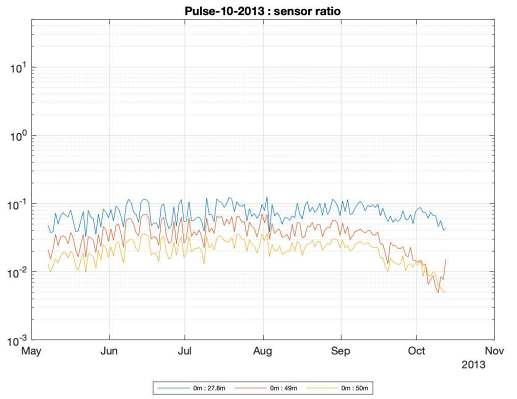
In this Version 2.0 of this report, we have instead implemented a visual check of the sensor ratios among the pairs of sensors to allow not only their relative values but also comparison of these across multiple pairs to be examined. These visualisations and the manual QC decisions based on them are detailed in section 5.2.1.

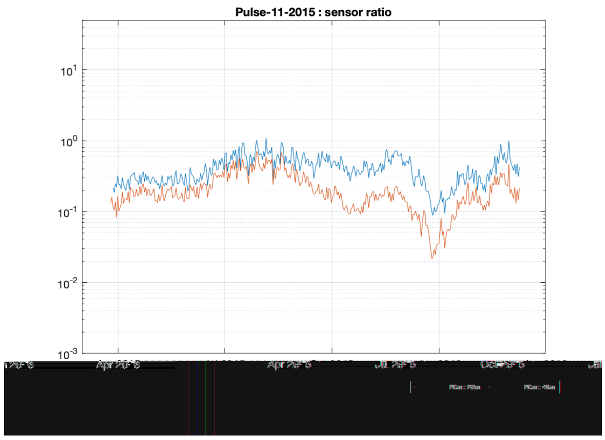
5.2.1 Plots of sensor ratios

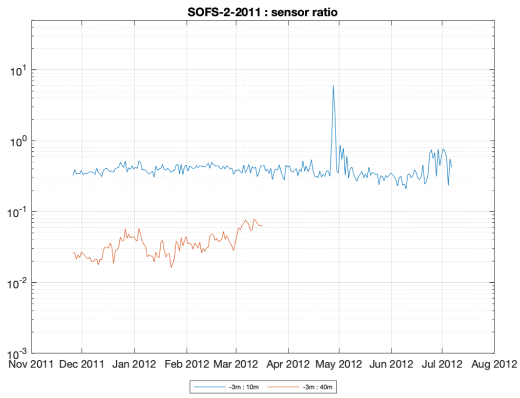


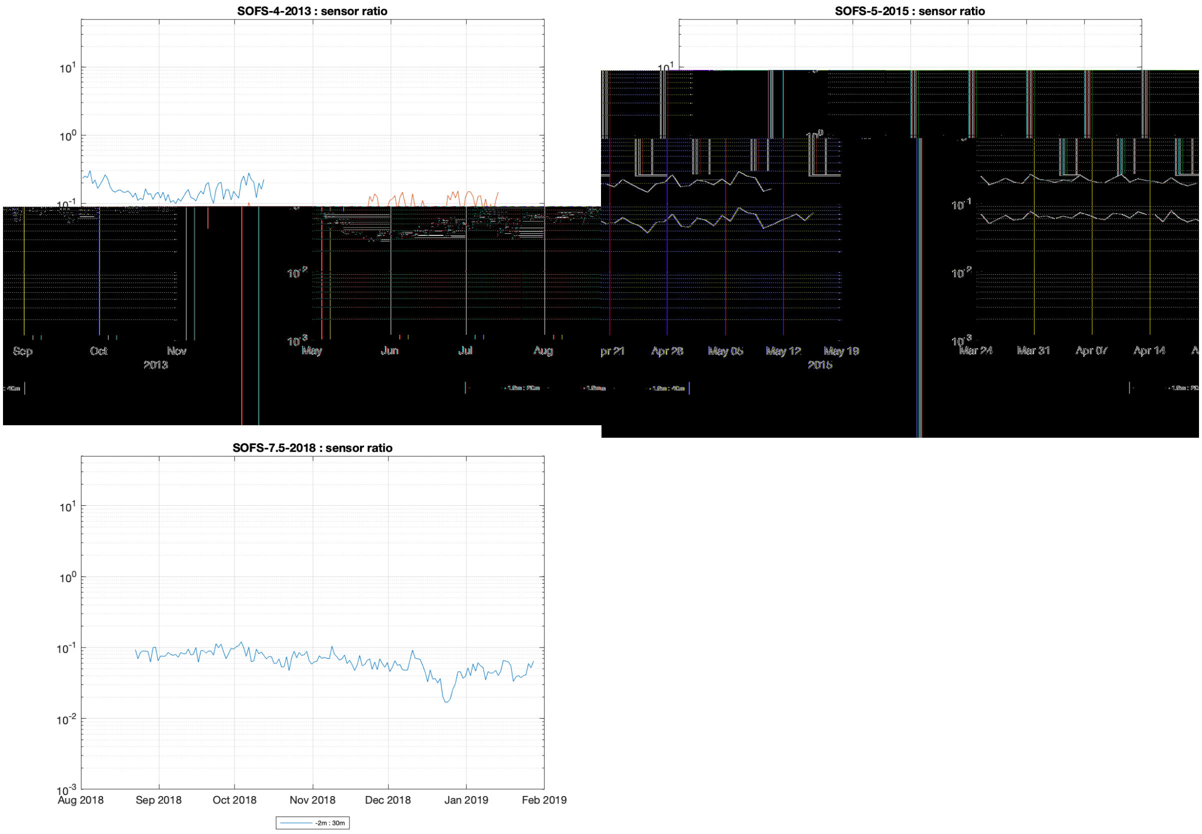












Manual QC decisions based on the Neighbour Test plots and inter-annual comparisons.

The following sensors were marked 3 (probably bad) after inspection of the nearest Neighbour plots, as well as from inter-annual variations as discussed below in Section 6.

Pulse-6

SN 200341 after 2009-09-22: sensor scaling incorrect, saturates

SN 200664 after 2010-01-02: bio-fouled, drops below deeper sensor

Pulse-7-2010

SN 200665 after 2011-02-01: bio-fouled, drops below deeper sensor

Pulse-8-2011

SN 200664 after 2011-10-01: bio-fouled, drops below deeper sensor

Pulse-11-2015

SN 082V023 after 2013-09-15: bio-fouled, drops below deeper sensor

SOFS-1-2010

SN Q40966 after 2010-03-05: sensor scaling issue

5.3 Flag statistics

Flags

PAR_quality_control : overall flag
PAR_quality_control_cl : climatology flag
PAR_quality_control_gr : global range flag
PAR_quality_control_io : in/out of water flag
PAR_quality_control_man : manual flagging

Table 5. Flag counts from each deployment for each test

deployment	instrument	Serial number	depth	flag	unknown	Good data	Probably good data	Probably bad data	Bad data	Not deployed	interpolated	Missing value
Pulse-6-2009	MDS-MKVL	200341	-0.1	Final	0	0	0	0	246304	15141	0	0
			-0.1	Cl	0	187534	58504	267	0	0	0	0
			-0.1	Gr	0	246305	0	0	0	0	0	0
			-0.1	Io	246304	0	0	0	0	15141	0	0
			-0.1	Man	0	0	0	0	246305	0	0	0
	MDS-MKVL	200664	27	Final	0	104754	33485	108125	0	15114	0	0
			27	Cl	0	187861	58504	0	0	0	0	0
			27	Gr	0	246365	0	0	0	0	0	0
			27	Io	246364	0	0	0	0	15114	0	0
			27	Man	138240	0	0	108125	0	0	0	0
	ECO-PAR	PARS-134	37.5	Final	0	3102	957	0	0	0	0	0
			37.5	Cl	0	3102	957	0	0	0	0	0
			37.5	Gr	0	4059	0	0	0	0	0	0
			37.5	Io	4059	0	0	0	0	0	0	0
	MDS-MKVL	200665	50	Final	0	187860	58504	0	0	15738	0	0
			50	Cl	0	187861	58504	0	0	0	0	0
			50	Gr	0	246365	0	0	0	0	0	0
			50	Io	246364	0	0	0	0	15738	0	0
SOFS-1-2010	LI-190SA	Q40966	-2.72	Final	0	0	0	0	7501	539	0	0
			-2.72	Cl	0	5578	1727	196	0	0	0	0
			-2.72	Gr	0	7501	0	0	0	0	0	0
			-2.72	Io	7501	0	0	0	0	539	0	0
			-2.72	Man	0	0	0	0	7501	0	0	0
	MDS-MKVL	201318	40	Final	0	161082	48167	0	0	1801	0	0
			40	Cl	0	161083	48167	0	0	0	0	0
			40	Gr	0	209250	0	0	0	0	0	0
			40	Io	209249	0	0	0	0	1801	0	0
Pulse-7-2010	MDS-MKVL	200341	0	Final	0	240242	73437	0	0	23360	0	0
			0	Cl	0	240243	73437	0	0	0	0	0

deployment	instrument	Serial number	depth	flag	unknown	Good data	Probably good data	Probably bad data	Bad data	Not deployed	interpolated	Missing value
			0	Gr	0	313680	0	0	0	0	0	0
			0	Io	313679	0	0	0	0	23360	0	0
	MDS-MKVL	200664	27	Final	0	240242	73437	0	0	23396	0	0
			27	Cl	0	240243	73437	0	0	0	0	0
			27	Gr	0	313680	0	0	0	0	0	0
			27	Io	313679	0	0	0	0	23396	0	0
	ECO-PARS	PARS-135	31	Final	0	4022	1206	0	0	444	0	0
			31	Cl	0	4022	1206	0	0	0	0	0
			31	Gr	0	5228	0	0	0	0	0	0
			31	Io	5228	0	0	0	0	444	0	0
	MDS-MKVL	200665	50	Final	0	154369	50110	109200	0	122990	0	0
			50	Cl	0	240243	73437	0	0	0	0	0
			50	Gr	0	313680	0	0	0	0	0	0
			50	Io	313679	0	0	0	0	122990	0	0
			50	Man	204480	0	0	109200	0	0	0	0
Pulse-8-2011	MDS-MKVL	200665	0	Final	0	387857	117388	0	0	6755	0	0
			0	Cl	0	387858	117388	0	0	0	0	0
			0	Gr	0	505246	0	0	0	0	0	0
			0	Io	505245	0	0	0	0	6755	0	0
	MDS-MKVL	200664	27	Final	0	65866	17593	421786	0	6755	0	0
			27	Cl	0	387858	117388	0	0	0	0	0
			27	Gr	0	505246	0	0	0	0	0	0
			27	Io	505245	0	0	0	0	6755	0	0
			27	Man	83460	0	0	421786	0	0	0	0
	ECO-PARS	PARS-134	33.8	Final	0	20201	6254	0	0	1364	0	0
			33.8	Cl	0	20201	6254	0	0	0	0	0
			33.8	Gr	0	26455	0	0	0	0	0	0
			33.8	Io	26455	0	0	0	0	1364	0	0
	MDS-MKVL	200341	50	Final	0	169764	51870	0	0	3541	0	0
			50	Cl	0	169765	51870	0	0	0	0	0
			50	Gr	0	221635	0	0	0	0	0	0
			50	Io	221634	0	0	0	0	3541	0	0
SOFS-2-2011	LI-190SA	Q40966	-3	Final	0	3794	1284	336	0	385	0	0
			-3	Cl	0	3794	1284	336	0	0	0	0
			-3	Gr	0	5414	0	0	0	0	0	0
			-3	Io	5414	0	0	0	0	385	0	0
	MDS-MKVL	201319	10	Final	0	132334	41155	0	0	14492	0	0
			10	Cl	0	132335	41155	0	0	0	0	0

deployment	instrument	Serial number	depth	flag	unknown	Good data	Probably good data	Probably bad data	Bad data	Not deployed	interpolated	Missing value
			10	Gr	0	173490	0	0	0	0	0	0
			10	Io	173489	0	0	0	0	14492	0	0
	MDS-MKVL	201318	40	Final	0	61717	20221	0	0	3601	0	0
			40	Cl	0	61718	20221	0	0	0	0	0
			40	Gr	0	81939	0	0	0	0	0	0
			40	Io	81938	0	0	0	0	3601	0	0
SOFS-3-2012	LI-190SA	Q40966	-2.8	Final	0	3155	942	0	1	672	0	0
			-2.8	Cl	0	3156	942	0	0	0	0	0
			-2.8	Gr	0	4097	0	0	1	0	0	0
			-2.8	Io	4098	0	0	0	0	672	0	0
Pulse-9-2012	ECO-PARS	PARS-135	38	Final	0	15956	4727	0	0	4479	0	0
			38	Cl	0	15956	4727	0	0	0	0	0
			38	Gr	0	20683	0	0	0	0	0	0
			38	Io	20683	0	0	0	0	4479	0	0
SOFS-4-2013	LI-190SA	Q47470	-1.8	Final	0	1395	905	1691	0	1278	0	0
			-1.8	Cl	0	1395	905	1691	0	0	0	0
			-1.8	Gr	0	3991	0	0	0	0	0	0
			-1.8	Io	3991	0	0	0	0	1278	0	0
	MDS-MKVL	201318	20	Final	0	81219	25471	0	0	4861	0	0
			20	Cl	0	81220	25471	0	0	0	0	0
			20	Gr	0	106691	0	0	0	0	0	0
			20	Io	106690	0	0	0	0	4861	0	0
	MDS-MKVL	201319	40	Final	0	185634	54060	0	0	16809	0	0
			40	Cl	0	185635	54060	0	0	0	0	0
			40	Gr	0	239695	0	0	0	0	0	0
			40	Io	239694	0	0	0	0	16809	0	0
Pulse-10-2013	MDS-MKVL	200341	0	Final	0	177561	52082	3	0	26805	0	0
			0	Cl	0	177561	52082	3	0	0	0	0
			0	Gr	0	229646	0	0	0	0	0	0
			0	Io	229646	0	0	0	0	26805	0	0
	ECO-PARS	PARS-134	27.8	Final	0	14772	4368	0	0	156	0	0
			27.8	Cl	0	14772	4368	0	0	0	0	0
			27.8	Gr	0	19140	0	0	0	0	0	0
			27.8	Io	19140	0	0	0	0	156	0	0
	DEFI-L	082V023	49	Final	0	177564	52082	0	0	26933	0	0
			49	Cl	0	177564	52082	0	0	0	0	0

deployment	instrument	Serial number	depth	flag	unknown	Good data	Probably good data	Probably bad data	Bad data	Not deployed	interpolated	Missing value
			49	Gr	0	229646	0	0	0	0	0	0
			49	Io	229646	0	0	0	0	26933	0	0
	MDS-MKVL	200665	50	Final	0	177564	52082	0	0	26735	0	0
			50	Cl	0	177564	52082	0	0	0	0	0
			50	Gr	0	229646	0	0	0	0	0	0
			50	Io	229646	0	0	0	0	26735	0	0
SOFS-5-2015	LI-190SA	Q47470	-1.8	Final	0	6706	2073	322	6	583	0	0
			-1.8	Cl	0	6711	2074	322	0	0	0	0
			-1.8	Gr	0	9101	0	0	6	0	0	0
			-1.8	Io	9107	0	0	0	0	583	0	0
	MDS-MKVL	201318	20	Final	0	55916	15070	0	0	3035	0	0
			20	Cl	0	55916	15070	0	0	0	0	0
			20	Gr	0	70986	0	0	0	0	0	0
			20	Io	70986	0	0	0	0	3035	0	0
	MDS-MKVL	201319	40	Final	0	61322	16543	0	0	3035	0	0
			40	Cl	0	61322	16543	0	0	0	0	0
			40	Gr	0	77865	0	0	0	0	0	0
			40	Io	77865	0	0	0	0	3035	0	0
Pulse-11-2015	MDS-MKVL	200665	20	Final	0	389500	118320	0	0	4980	0	0
			20	Cl	0	389500	118320	0	0	0	0	0
			20	Gr	0	507820	0	0	0	0	0	0
			20	Io	507820	0	0	0	0	4980	0	0
	ECO-PAR	PARS-134	28	Final	0	6623	1991	0	0	242	0	0
			28	Cl	0	6623	1991	0	0	0	0	0
			28	Gr	0	8614	0	0	0	0	0	0
			28	Io	8614	0	0	0	0	242	0	0
	DEFI-L	082V022	49	Final	0	398182	120822	0	0	20946	0	0
			49	Cl	0	398182	120822	0	0	0	0	0
			49	Gr	0	519004	0	0	0	0	0	0
			49	Io	519004	0	0	0	0	20946	0	0
FluxPulse-1-2016	LI-190SA	Q40966	-1.8	Final	0	1831	525	0	1	977	0	0
			-1.8	Cl	0	1832	525	0	0	0	0	0
			-1.8	Gr	0	2356	0	0	1	0	0	0
			-1.8	Io	2357	0	0	0	0	977	0	0
SOFS-6-2017	LI-190SA	Q47470	-1.8	Final	0	2837	1070	1083	455	1199	0	0
			-1.8	Cl	0	3169	1193	1083	0	0	0	0

deployment	instrument	Serial number	depth	flag	unknown	Good data	Probably good data	Probably bad data	Bad data	Not deployed	interpolated	Missing value
			-1.8	Gr	0	4990	0	0	455	0	0	0
			-1.8	Io	5445	0	0	0	0	1199	0	0
SOFS-7-2018	LI-190SA	Q47470	-1.8	Final	0	184	61	0	0	560	0	0
			-1.8	Cl	0	184	61	0	0	0	0	0
			-1.8	Gr	0	245	0	0	0	0	0	0
			-1.8	Io	245	0	0	0	0	560	0	0
SOFS-7.5-2018	LI-190SA	Q47470	-2	Final	0	2815	905	33	0	1292	0	0
			-2	Cl	0	2815	905	33	0	0	0	0
			-2	Gr	0	3753	0	0	0	0	0	0
			-2	Io	3753	0	0	0	0	1292	0	0
	ECO-PARS	PARSB-419	30	Final	0	19460	6015	0	0	795	0	0
			30	Cl	0	19460	6015	0	0	0	0	0
			30	Gr	0	25475	0	0	0	0	0	0
			30	Io	25475	0	0	0	0	795	0	0

6 Discussion and recommendations

6.1 QARTOD tests that were not performed:

Some of the recommended QARTOD tests were deemed not applicable to the PAR data. As all the sensors are mounted at discrete depths on the mooring, tests related to depth profiles (Test 5 and Test 6 in Table 3) were not conducted.

Given that PAR values can change rapidly within a short period of time, a spike test was also not deemed useful. It would be difficult to differentiate a spike due to a problem with a sensor from natural changes in PAR, e.g. due to clouds covering or uncovering the sun, or wave focusing.

Similarly, the attenuated signal test cannot readily be adapted to the PAR data as it would be difficult to distinguish attenuation of the signal due to biofouling from attenuation due to periods of predominantly overcast conditions, as frequently observed in the Southern Ocean.

6.2 Main causes for data flagging and associated uncertainties

The most common reasons for data concern (flag 3) were showing too high

values in the Climatology test or values which did not display oceanographic consistency in the manual Neighbour test, i.e. the values were either higher than those from shallower sensors or lower than those from deeper sensors. The Neighbour Test was also the most common reason for data rejection (flag 4) which occurred when 1 sensor failed against multiple other sensors. The flagging of data by these tests is shown for all sensors in the plots in Section 8.

6.3 Did the QC tests work and how good are the data?

Evaluating the success of the tests requires determining whether they correctly identified and flagged only and all *truly* bad data (flag 4) and possibly bad data (flag 3) and retained only and all *truly* good (flag 1) data. This requires some independent understanding of which data is good. We examined this in several ways, as described in sections 6.3.1, 6.3.2, and 6.3.3.

6.3.1 Comparison to in-air shortwave sensors on the SOFS moorings

First the PAR fraction was estimated from the shortwave sensors, using the same expressions as for conversion of the modelled top of atmosphere insolation in the climatology test. Then plots of the ratio of the in-air PAR sensors to these shortwave-based PAR estimates were examined (plots are shown in Section 7). For the in-air sensors a ratio of 1 is expected, and often occurred. But some sensors were offset by 30-50%. This gives an indication of the relative accuracy of the sensors and interannual variations constructed from them. In general, these plots reveal very good agreement between the LiCor planar PAR sensors and the shortwave planar sensors, and also show that the spherical Alec sensors have higher values by ~2x as expected from geometrical considerations (with deviations that are highest in winter when the incident angle is low and reflections are more problematic).

6.3.2 Comparison to expected PAR values at depth

This is based on estimates for the PAR attenuation coefficient for reasonable values of biomass loading. In Version 1.0 of this report, this was done as an extension of the climatology test (which set upper bounds on PAR at depth using the blue water attenuation coefficient value of $K_d = 0.04$), and consisted of calculating two other K_d estimates of 0.12 and 0.15 for chlorophyll levels of 0.5 and 1.0 µg L^{-1}, respectively, using the equations of Morel et al., (2007):

Table 6 typical Kd values for chlorophyll *a* concentration

chl (ug L-1)	*kd (490)*	*kd (PAR)*
0.03	0.02	0.05
0.5	0.07	0.12
1	0.09	0.15
5.6	0.26	0.30

$$\boldsymbol{K_d(PAR)_2 = 0.0665 + 0.874\, K_d(490) - 0.00121[K_d(490)]^{-1}}$$

$$\boldsymbol{K_d(490) = 0.0166 + 0.0773[Chl]^{0.6715}}$$

These choices of Chl values were based on sparse in-situ HPLC pigment analyses at the SOTS site and satellite remote sensing estimates which suggest that maximum chlorophyll *a* concentrations are typically ~0.6 µg L^{-1} (Eriksen et al., 2018). These Kd values were then used to calculate expected PAR values at depth to which the data were compared to assess whether the observed PAR values were reasonable (and in general they were – see the Version 1.0 report).

In this Version 2.0 report, we have modified the approach to compare observed and expected K_d values (rather than PAR values) and have used Chl estimates based on in-situ fluorescence measurements from the SOTS moorings to calculate expected K_d values. The observed K_d values were calculated from sensor ratios relative to the surface short wave radiation sensor (after conversion to umol m^{-2} s^{-1} of PAR). The expected K_d values were calculated using the equations of Morel et al., (2007) from the chlorophyll measured at night by the FLNTUS sensor, after multiplying the sensor output by a scale factor of 0.32 as estimated from comparison to HPLC pigment analyses, as detailed in Schallenberg et al. (2019).

These observed and expected K_d values are shown in Figure 6. In general, they suggest that the low PAR values at depth can be understood as the result of attenuation by overlying biomass (rather than bio-fouling). Specifically, the K_d values based on the sensor pairs ranged from 0.04 (the blue water value) to 0.25, and the K_d values based on the FLNTUS chlorophyll estimates ranged from 0.04 to 0.21. The highest K_d values from the PAR sensor pairs do correspond with times of suspected bio-fouling based on the Neighbour test (see section 5). The plots also show that the observed lower seasonal amplitude of PAR variations at depth compared to at the surface is expected based on the seasonal cycle of chlorophyll. Interestingly, the FLNTUS based K_d estimates shown larger seasonality than the PAR based K_d estimates, which could arise from community or physiological variations (Schallenberg et al., 2019).

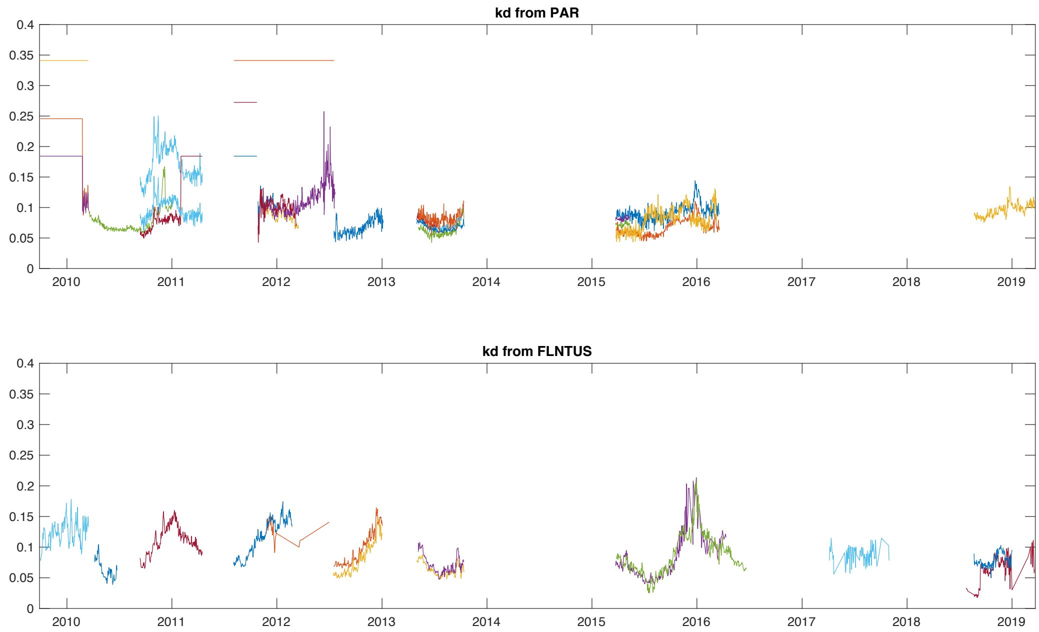


Figure 6 Top Panel, Kd from PAR/SWR : Bottom Panel Kd from FLNTUS data. The high K_d values in 2011 (upper light blue) is the Pulse-7 sensor at 27m, which based on this comparison reads low (higher Kd) as evident in the plots in section 5.2.1

6.3.3 Examination of multi-year records for consistency

The plots of the in-air PAR sensors across all years (Figure 7) suggested that the SOFS-1 data were unusually low and the Pulse-6 data were unusually high, and caused us to review these results. It was found that installation of the SOFS-1 sensor had not included a required resistor and that there was no way to assuredly re-scale for this error. Accordingly, all the SOFS-1 in-air PAR data was manually flagged 4. Comparison to the shortwave sensor on this mooring (see plots in Section 8) suggests it had a constant offset that could be corrected, but this was not pursued since it is more direct to simply use shortwave sensor data if a PAR estimate is required for SOFS-1. Review of the Pulse 6 in-air sensor calibration showed that its calibration values as provided by the manufacturer were unusual, and accordingly all its data were manually flagged 3 (as corrected data could be estimated in principle using a later sensor calibration).

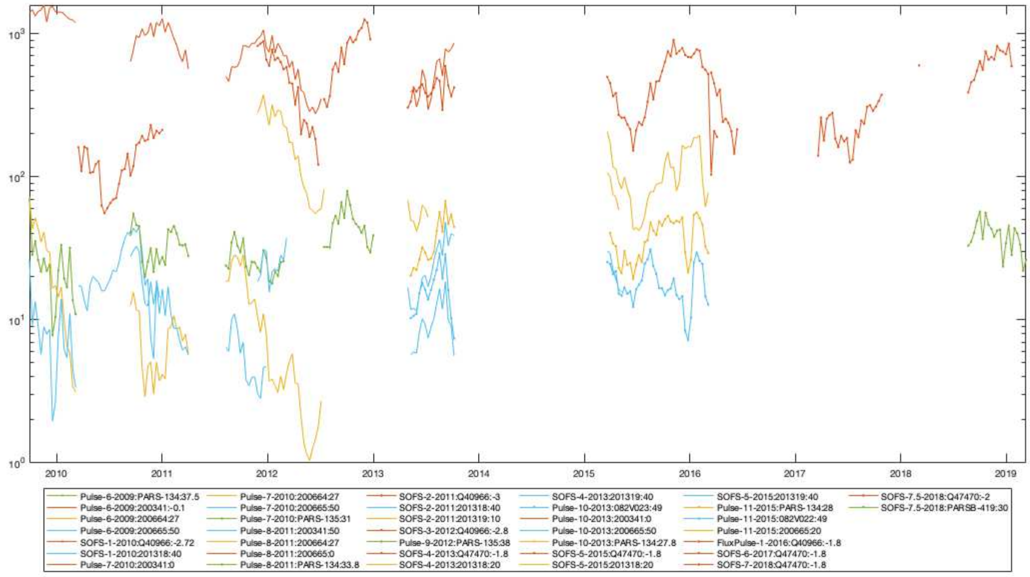


Figure 7. Daily daylight mean PAR values from surface sensors deployed at different times; note logarithmic scale on the y-axis. The mean PAR in summer for the SOFS 1 surface sensor was significantly lower than the records from other sensors placed at the same position in different years. Also note that the spherical sensor on Pulse 6 produces consistently higher summer values than the cosine sensors on the SOFS moorings. Based on these differences, review or those sensor results led to their flagging as suspect (flag 3). See Section 6 for Discussion.

6.4 Could the QC tests be improved? What are the implications for QA?

A challenging obstacle to more thorough quality control of this dataset is the difficulty of distinguishing sensor issues from the impact of cloudy days on the PAR observations (and the full shortwave radiation observations). The QC effort could be improved if reliable cloudiness estimates become available to be used in tests or at least in evaluations.

Similarly, it is difficult to evaluate whether low PAR values at depth derive from biomass loading in the water column or from biofouling on the sensors. This problem favours the choice of wiped sensors, but with recognition that even they are not always immune from fouling.

There were many points that were flagged as suspect in the Neighbour test due to a sensor at a shallower depth producing lower PAR values. It is difficult for this pairwise test to show which of these sensors is at fault. It some cases, plots of the data help to discern the sensor most likely to be at fault, based on deviations from seasonal expectations (see plots in Section 7).

The multi-year consistency evaluations discussed in section 6.3.3 were important in recognizing several problems missed by the implemented QARTOD. In future years, it may be possible for an improved PAR climatology based in part on the SOTS observations to improve the bounds set on the Gross Range and Climatology test. Nonetheless, many aspects of this first evaluation of the PAR data emphasize that delayed mode QC requires dedicated visualization beyond what can be achieved with QARTOD type tests.

A few overall recommendations for Quality Assurance have emerged from the QC:

1. Check all sensor calibrations against the growing record of calibrations to verify that none are unusual and thus potentially suspect.
2. Favour wiped sensors over unwiped sensors.
3. Pair sensors whenever possible, and favour deploying pairs of sensors at a few depths over single sensors at more depths.
4. Compare all sensors against the shortwave sensors before and after deployment.

6.5 Which data should you use?

We recommend that you use all PAR data with flag values of 2 or less. This is because none of this data has failed a QC test (the only reason that a flag value of 2 has been assigned is that one or more of the tests could not be performed). For in-air PAR estimates, we recommend that the shortwave sensor measurements are likely to provide the highest quality estimates, after scaling to units of PAR as in the Climatology test. For in-water PAR estimates, it is important to recognize that the flat (cosine-response) sensors and the spherical sensors measure different quantities, and thus these should not be directly compared or combined (e.g. to estimate attenuation).

7 Plots of PAR vs. Shortwave comparisons

This section shows sets of 3 plots for all sensors deployed in each year, in chronological order.

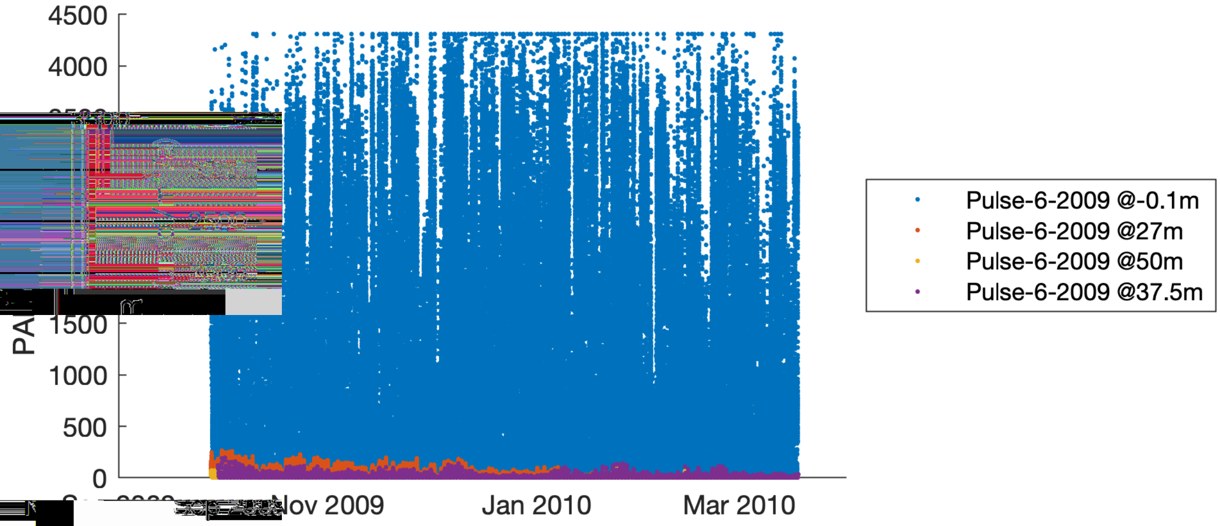
The top plots show the all the PAR sensor data.

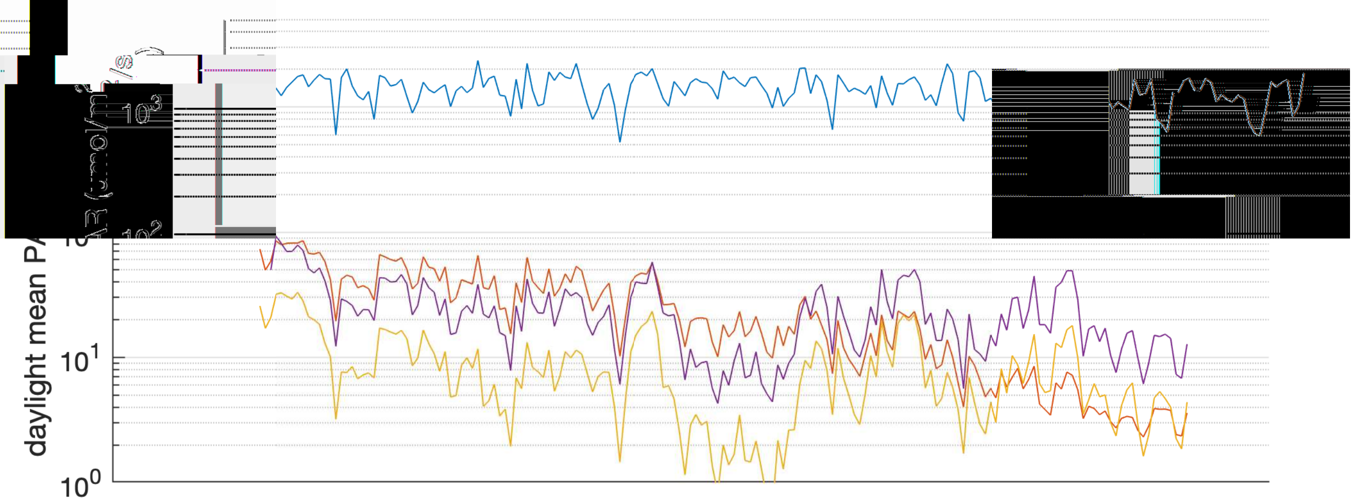
The middle plots show the daylight mean PAR values.

The bottom plots show the ratio of the daylight mean PAR values to the daylight mean ocean surface shortwave values

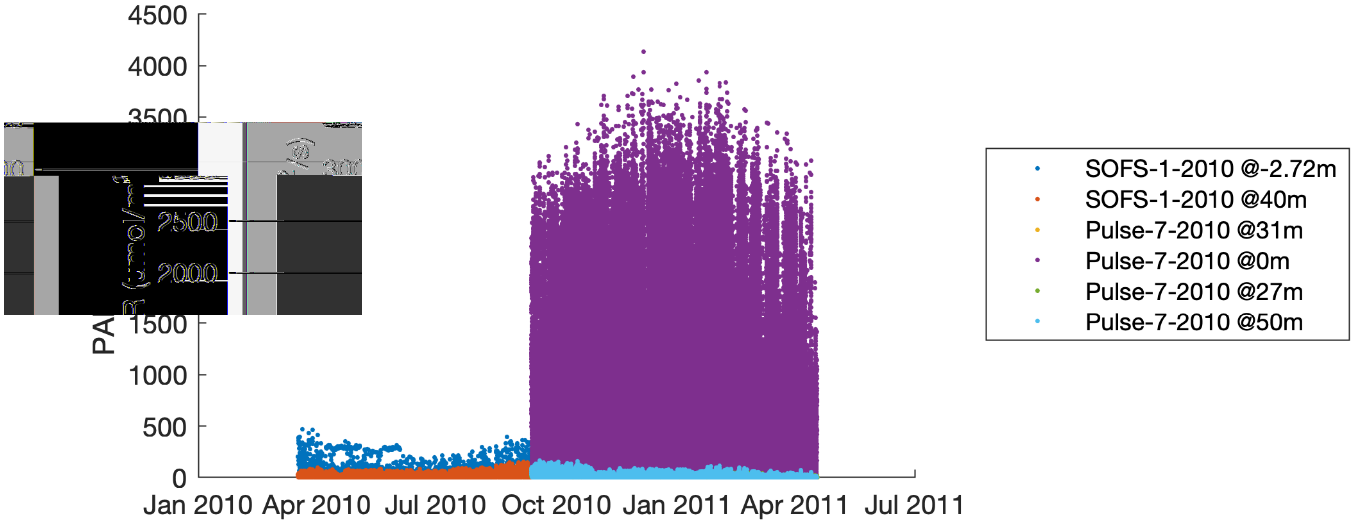
For surface PAR sensors the ratios in the bottom plots should be 1; departures from 1 are ~30-50% and indicate the approximate relative accuracies of the sensors, including differences in light collection by spherical and flat sensors. For both surface and deep sensors this ratio should be invariant with time. The observed temporal drifts in this ratio provide an indication of possible problems such as sensitivity changes or fouling.

Celestial seasonal cycles are expected at the surface, with attenuation of both the mean signal and its seasonality expected at depth.

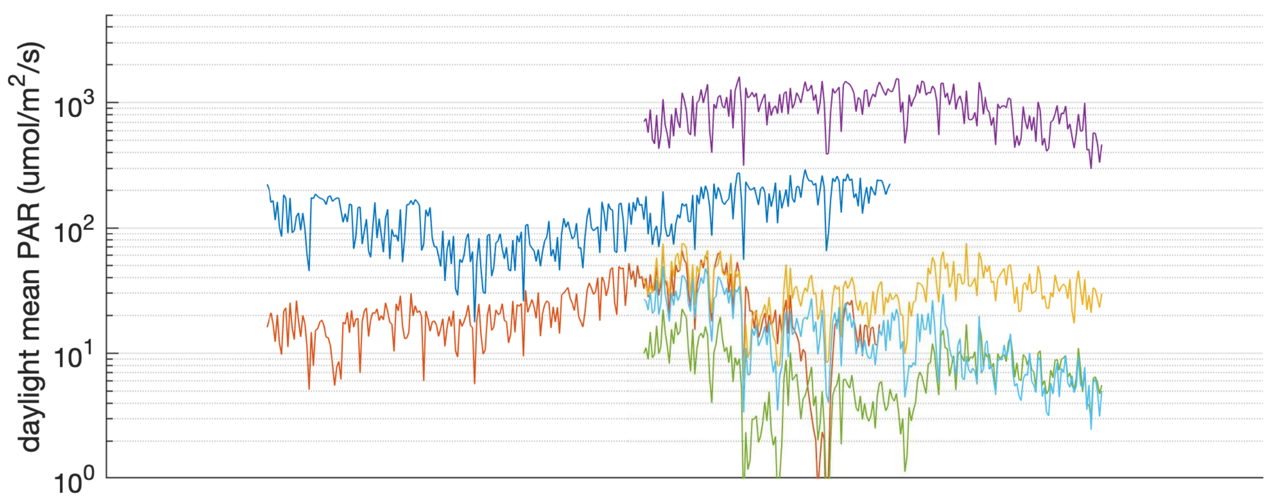

4500
4000
1500
1000
500
0
Nov 2009
Jan 2010
Mar 2010
Pulse-6-2009 @-0.1m
Pulse-6-2009 @27m
Pulse-6-2009 @50m
Pulse-6-2009 @37.5m


daylight mean PA
10^1
10^0

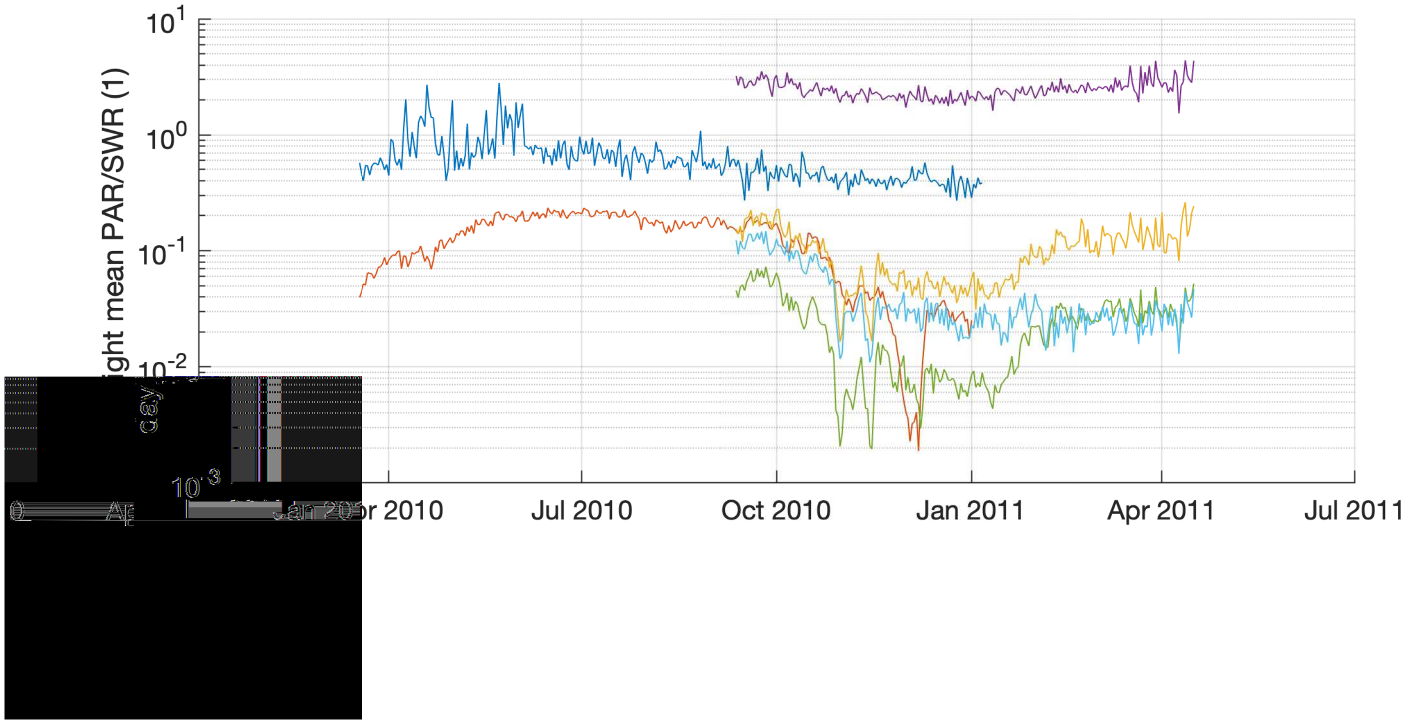

daylight mean PAR/SWR (1)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
Nov 2009
Dec 2009
Jan 2010
Feb 2010
Mar 2010
Apr 2010



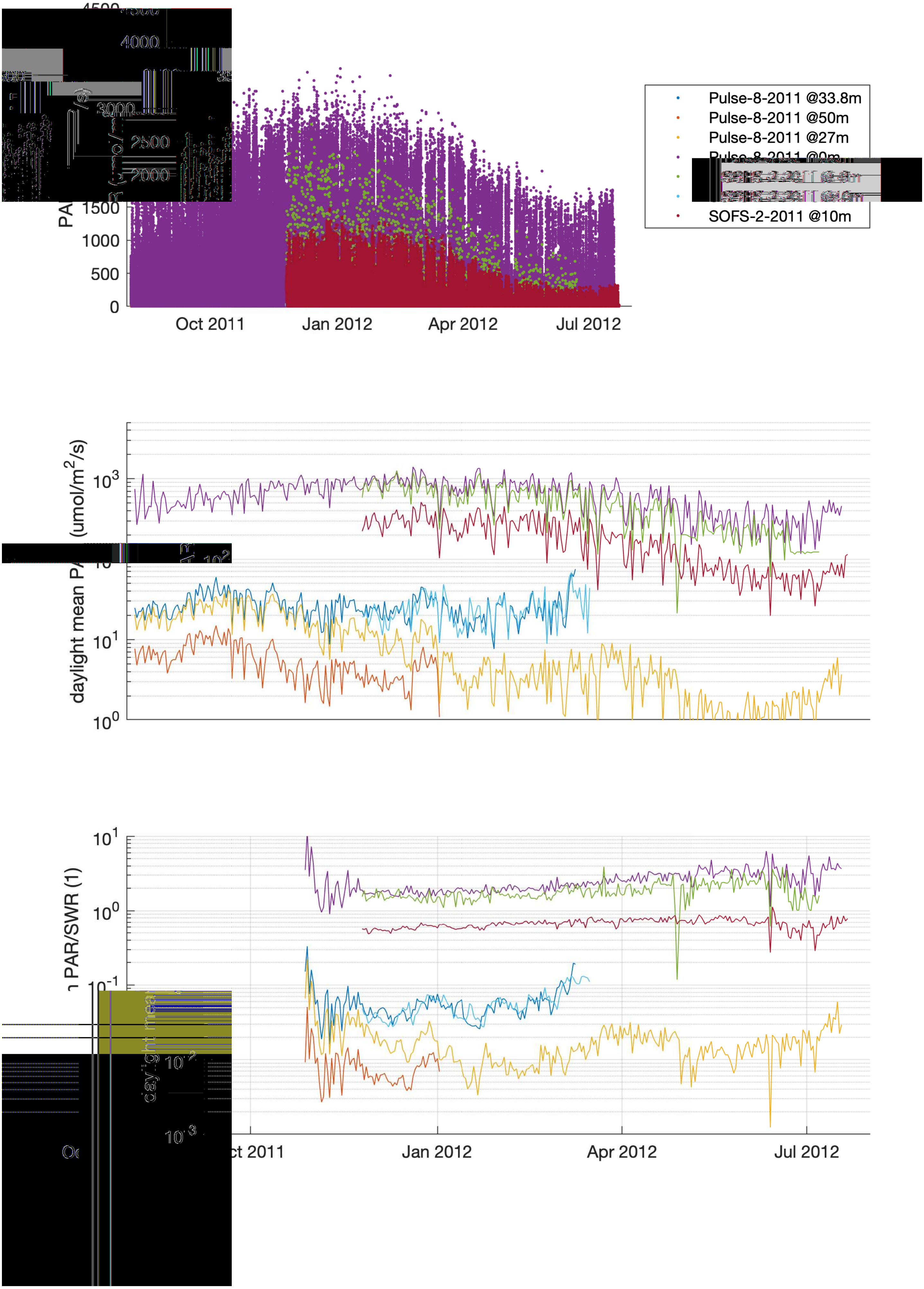
4500
4000
3500
1500
1000
500
0
PA
Jan 2010
Apr 2010
Jul 2010
Oct 2010
Jan 2011
Apr 2011
Jul 2011
SOFS-1-2010 @-2.72m
SOFS-1-2010 @40m
Pulse-7-2010 @31m
Pulse-7-2010 @0m
Pulse-7-2010 @27m
Pulse-7-2010 @50m



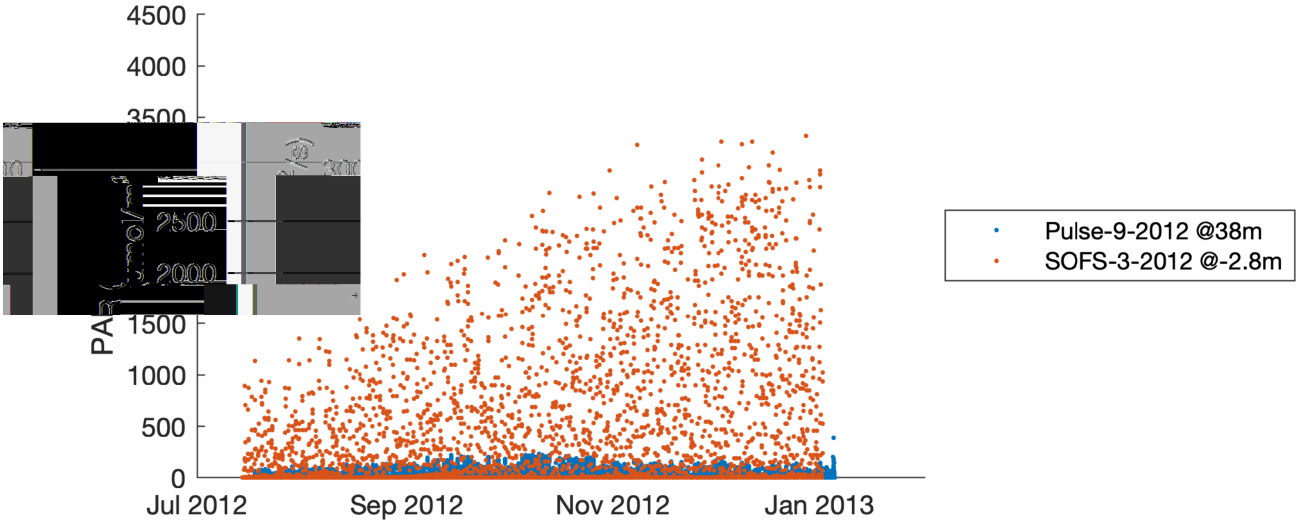
daylight mean PAR (umol/m^2/s)
10^3
10^2
10^1
10^0

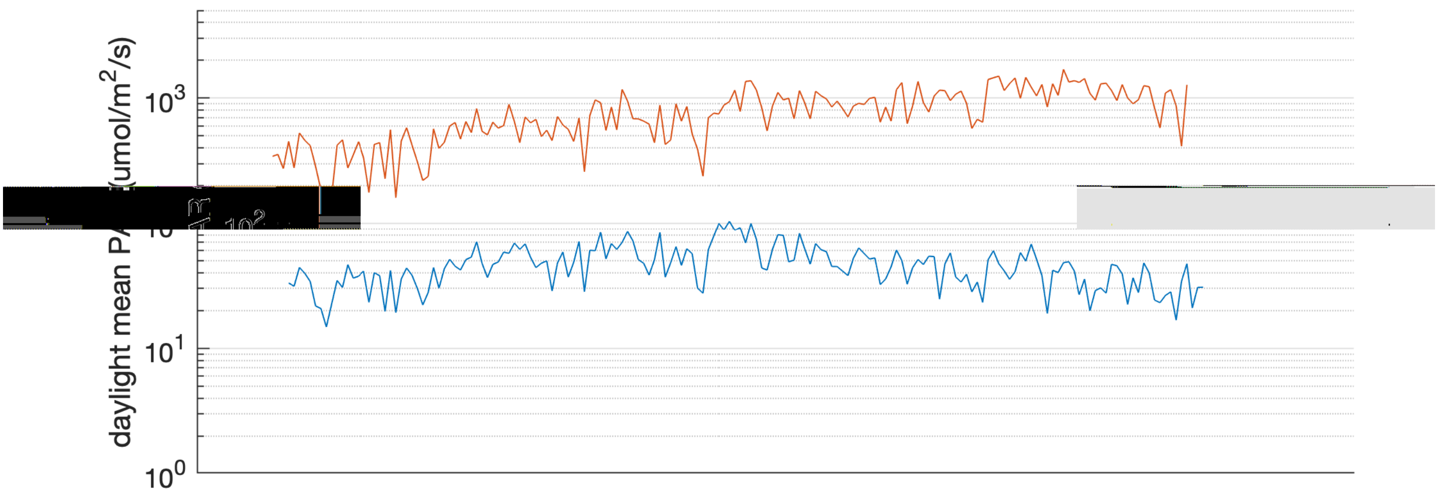


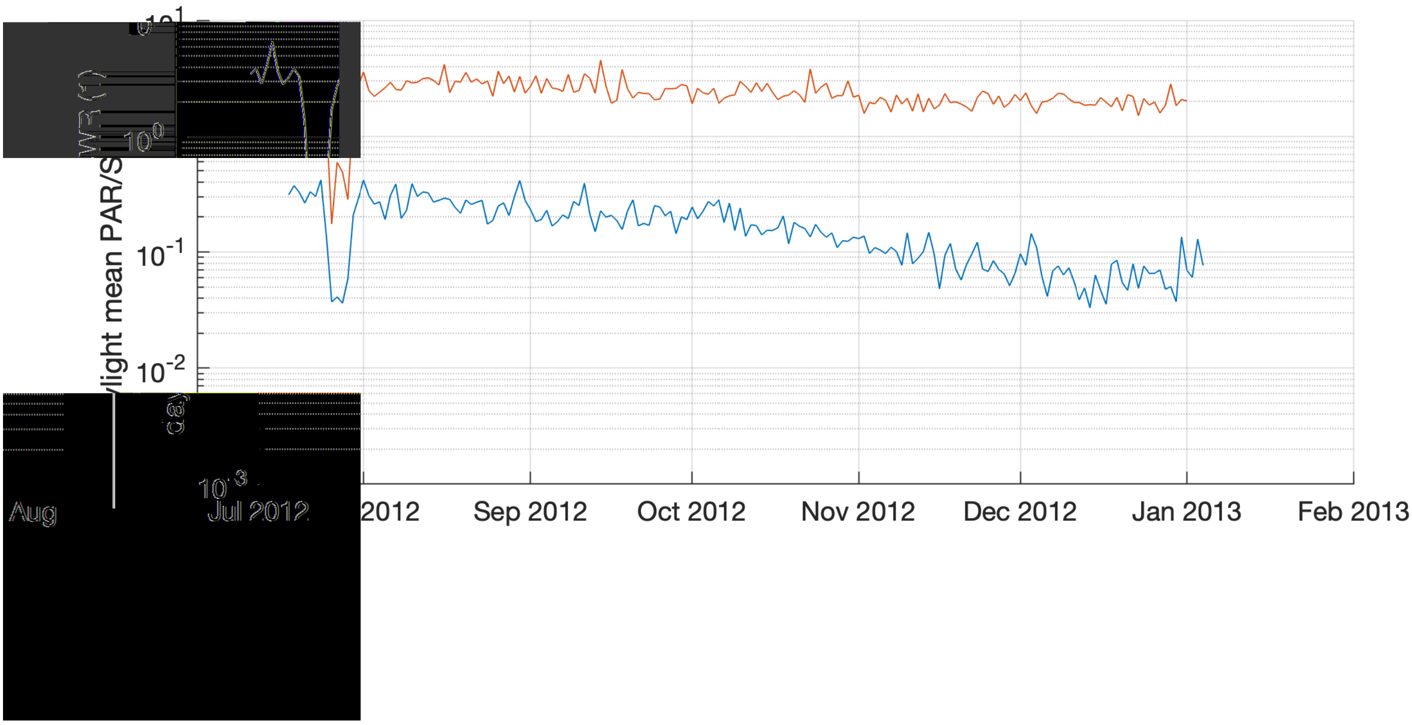
ight mean PAR/SWR (1)
10^1
10^0
10^-1
10^-2
Jul 2010
Oct 2010
Jan 2011
Apr 2011
Jul 2011

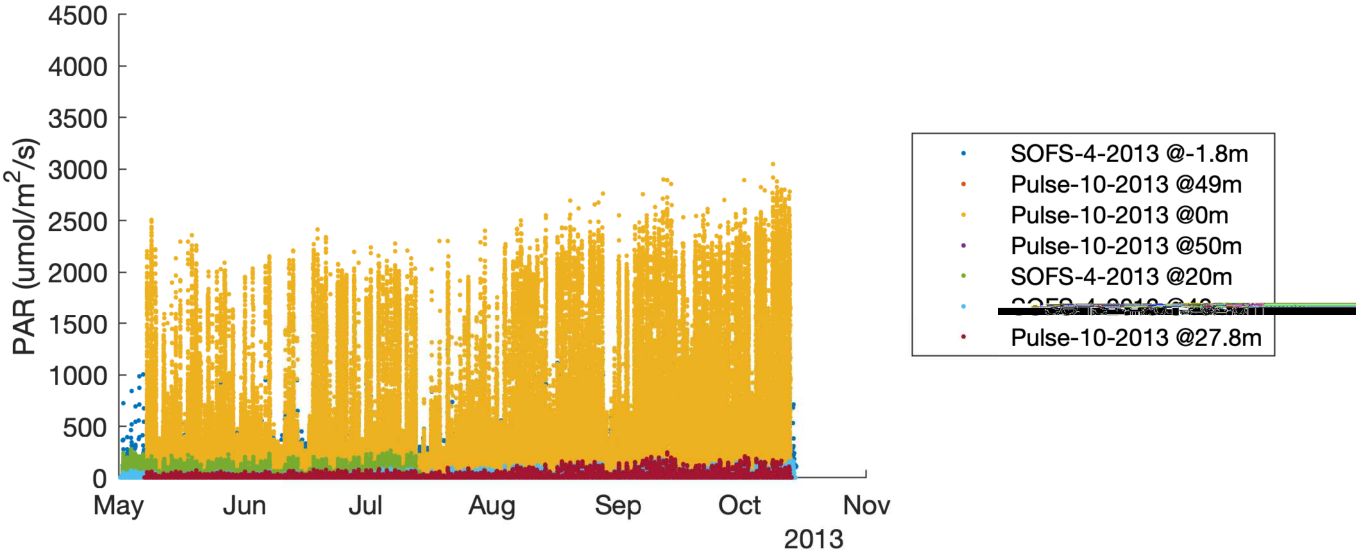


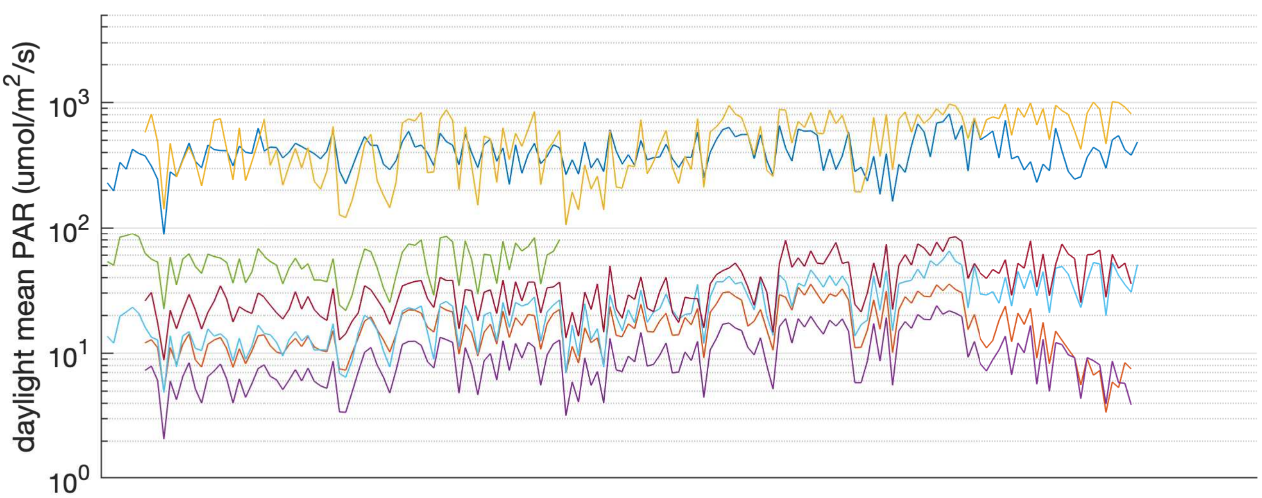
1500
1000
500
0
Oct 2011
Jan 2012
Apr 2012
Jul 2012
Pulse-8-2011 @33.8m
Pulse-8-2011 @50m
Pulse-8-2011 @27m
SOFS-2-2011 @10m
daylight mean PAR (umol/m^2/s)
10^3
10^1
10^0
PAR/SWR (1)
10^1
10^0
10^-1
Jan 2012
Apr 2012
Jul 2012

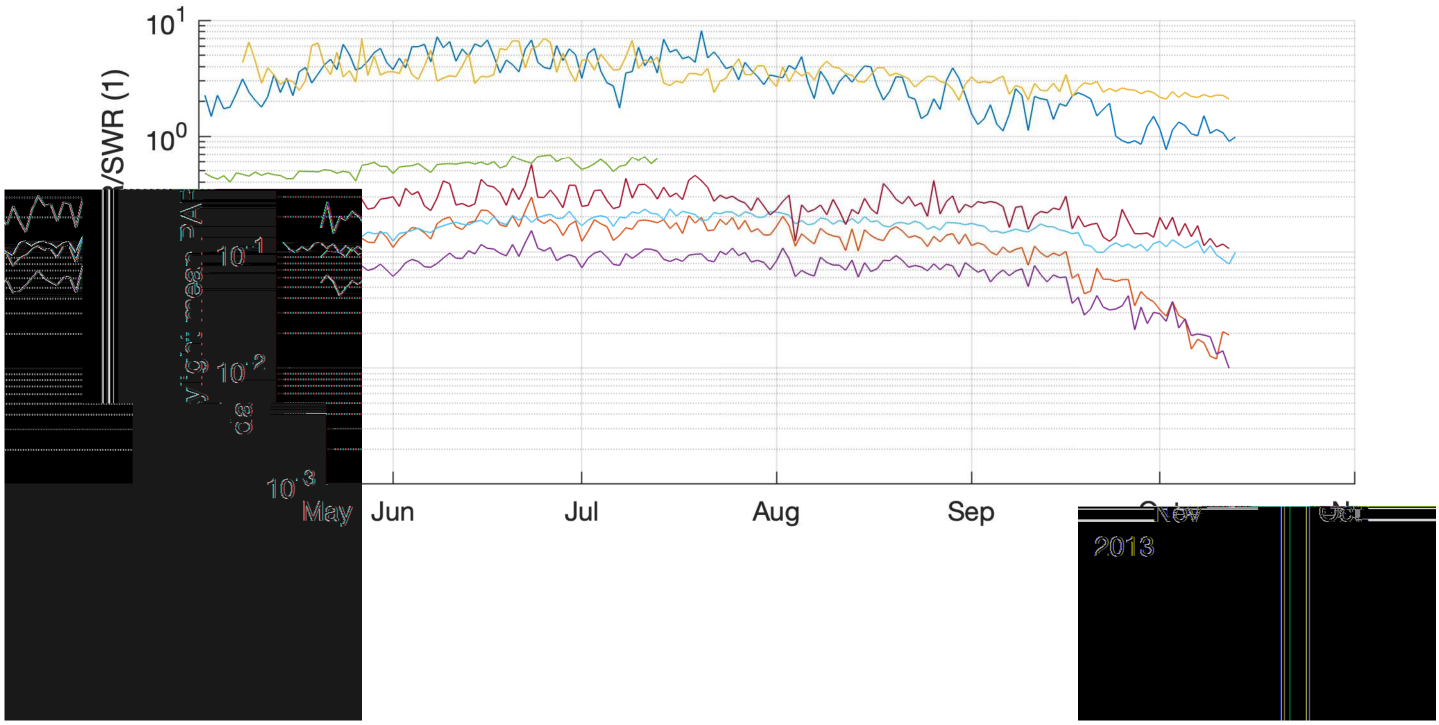

4500
4000
3500
2500
2000
1500
1000
500
0
PAR (umol/m²/s)
Jul 2012
Sep 2012
Nov 2012
Jan 2013
Pulse-9-2012 @38m
SOFS-3-2012 @-2.8m

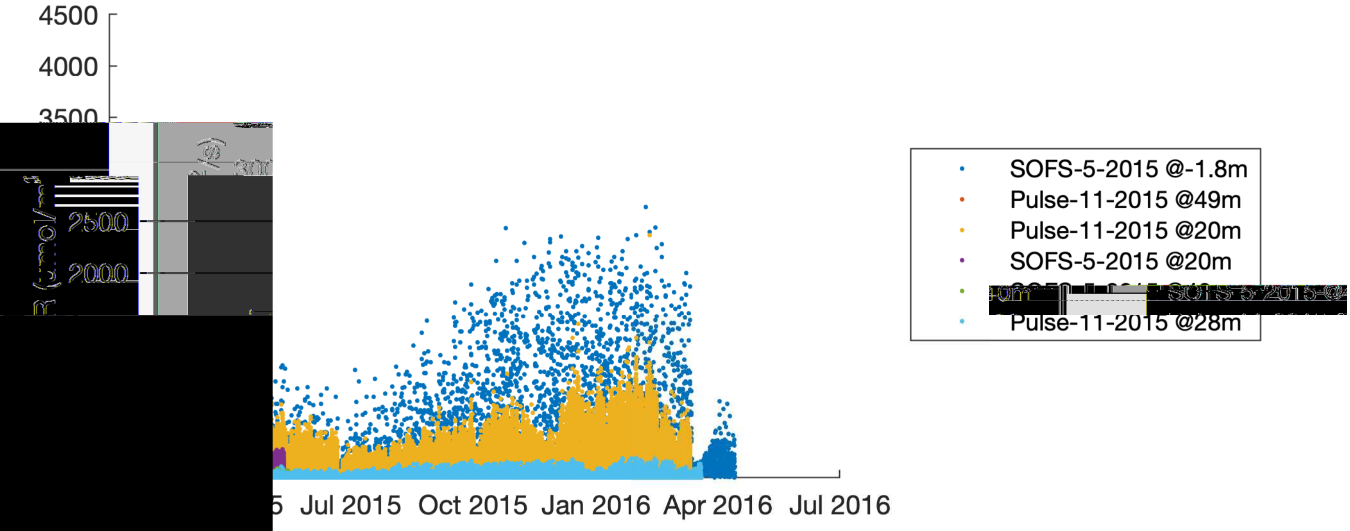

daylight mean PAR (umol/m²/s)
10³
10²
10¹
10⁰

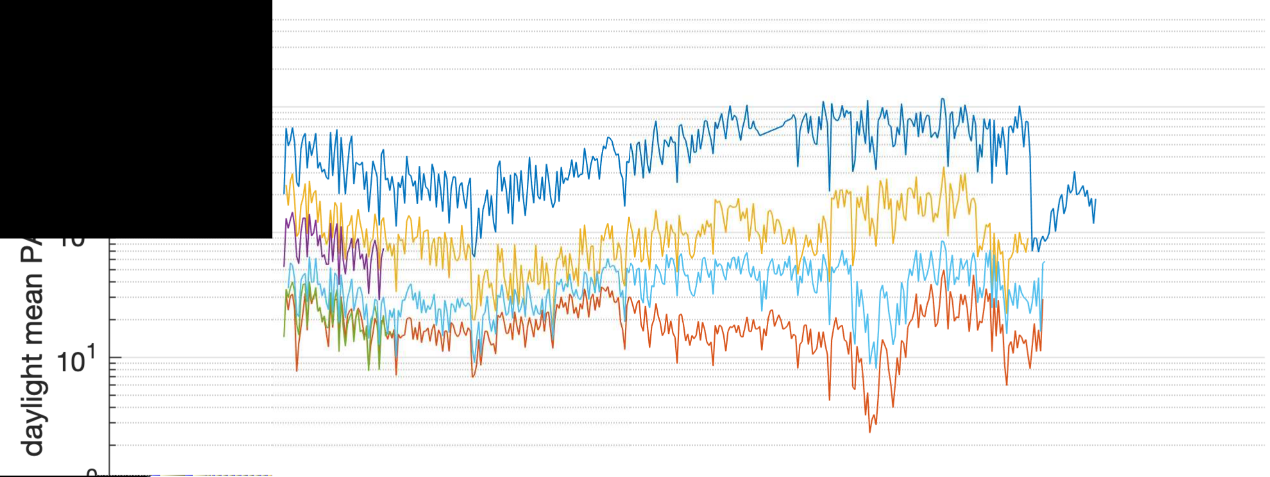

daylight mean PAR/SWR (1)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
Jul 2012
Aug 2012
Sep 2012
Oct 2012
Nov 2012
Dec 2012
Jan 2013
Feb 2013

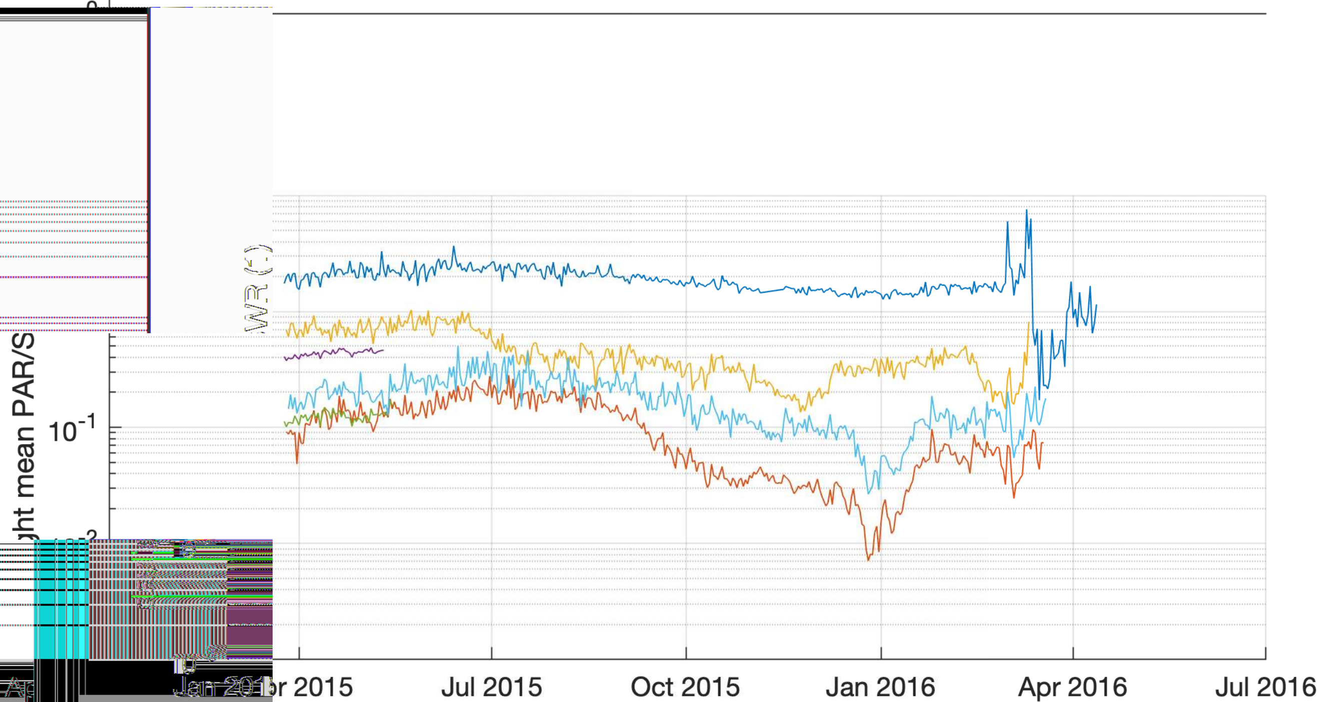

PAR (umol/m^2/s)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
May
Jun
Jul
Aug
Sep
Oct
Nov
2013
SOFS-4-2013 @-1.8m
Pulse-10-2013 @49m
Pulse-10-2013 @0m
Pulse-10-2013 @50m
SOFS-4-2013 @20m
Pulse-10-2013 @27.8m

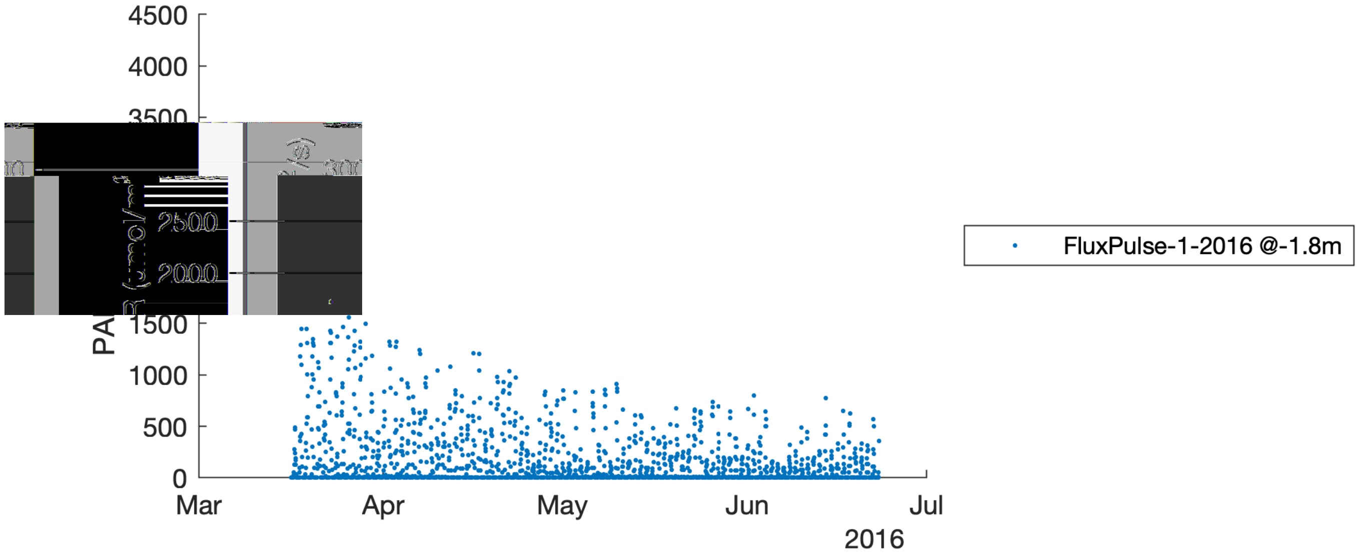

daylight mean PAR (umol/m^2/s)
10^3
10^2
10^1
10^0

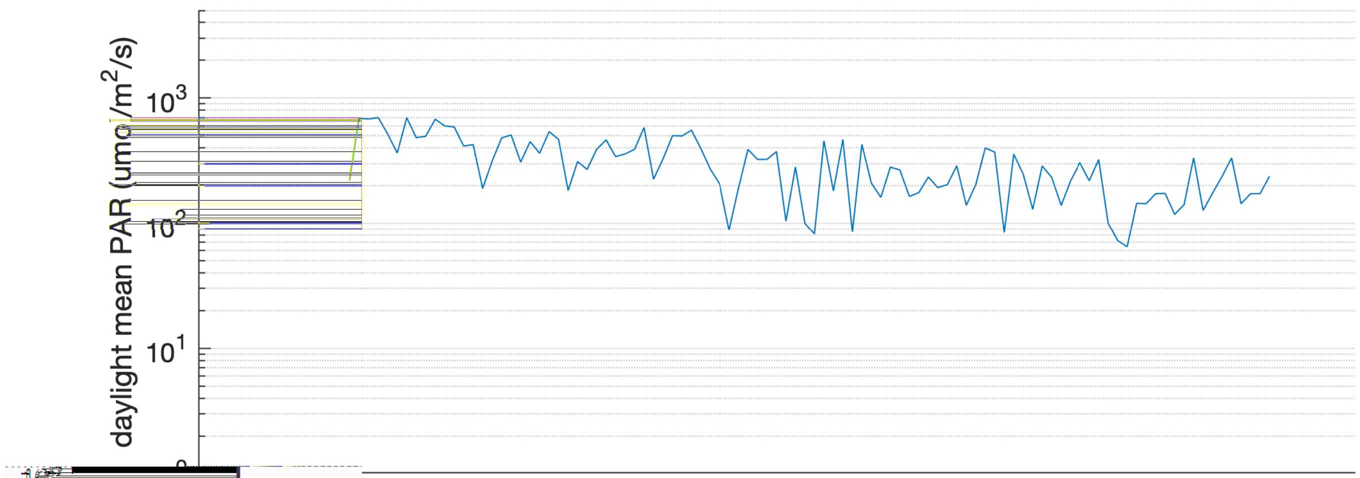

10^1
10^0
Jun
Jul
Aug
Sep

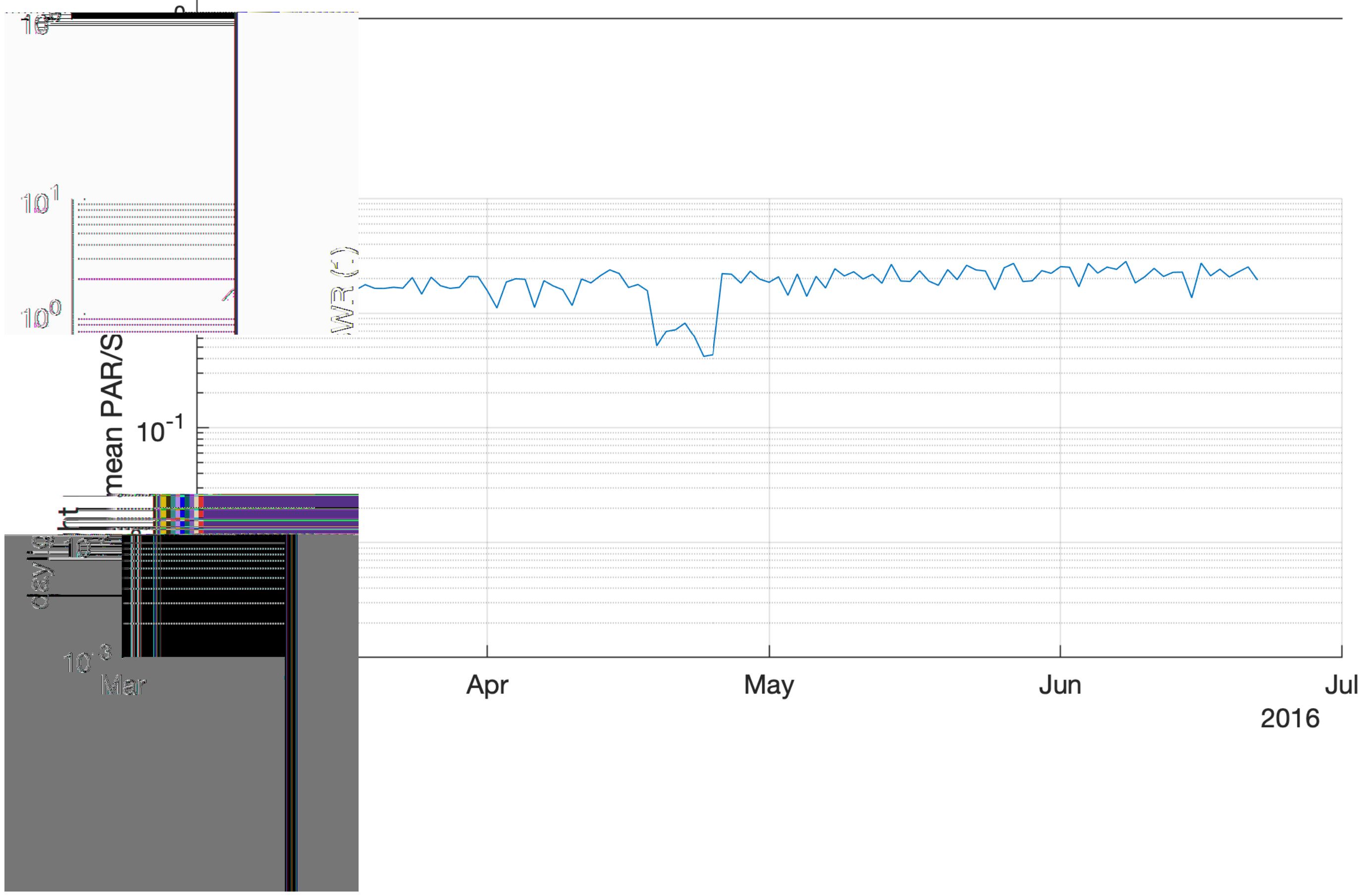

4500
4000
2500
2000
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
SOFS-5-2015 @-1.8m
Pulse-11-2015 @49m
Pulse-11-2015 @20m
SOFS-5-2015 @20m
Pulse-11-2015 @28m

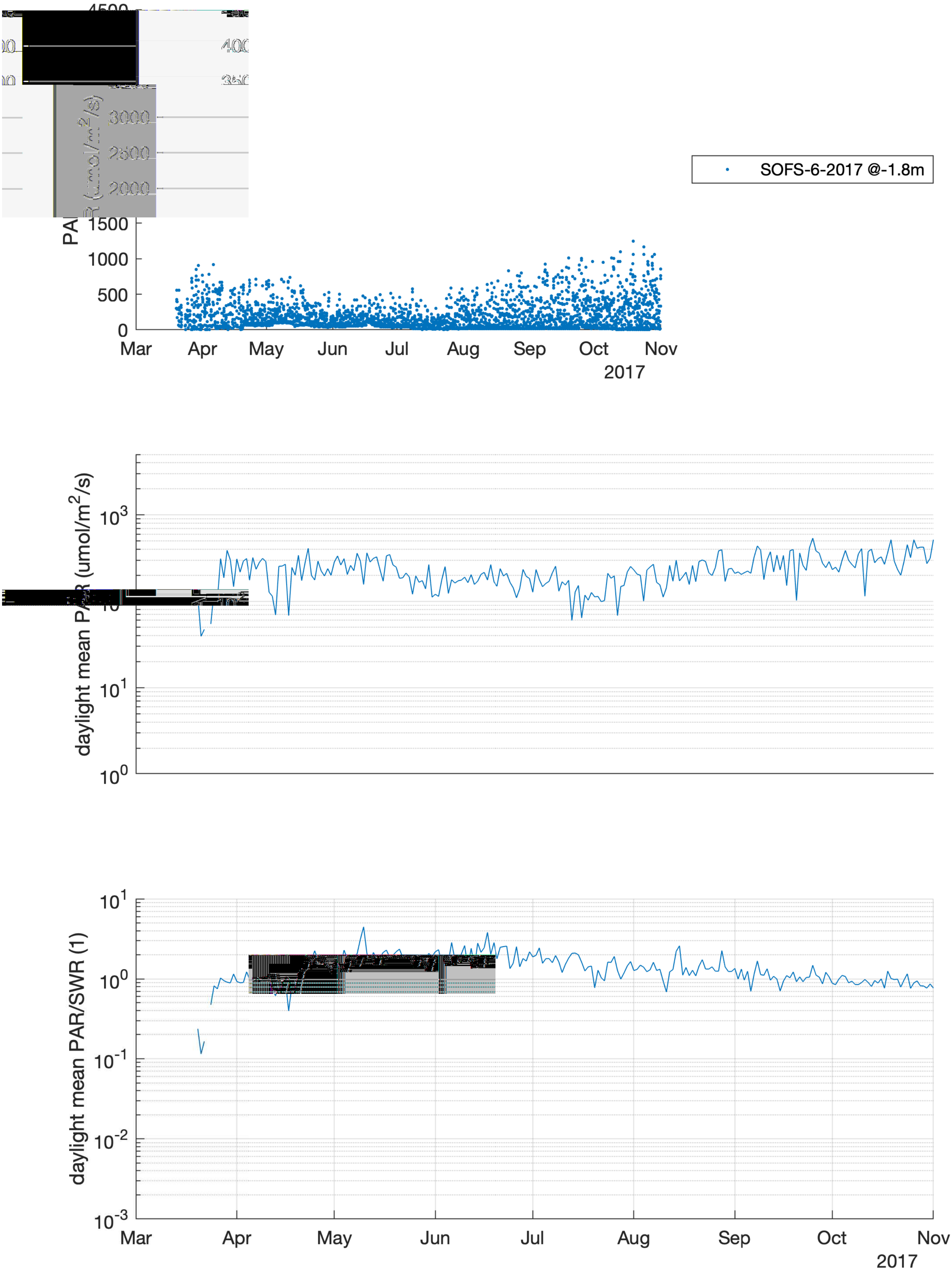

10^1


10^{-1}
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016

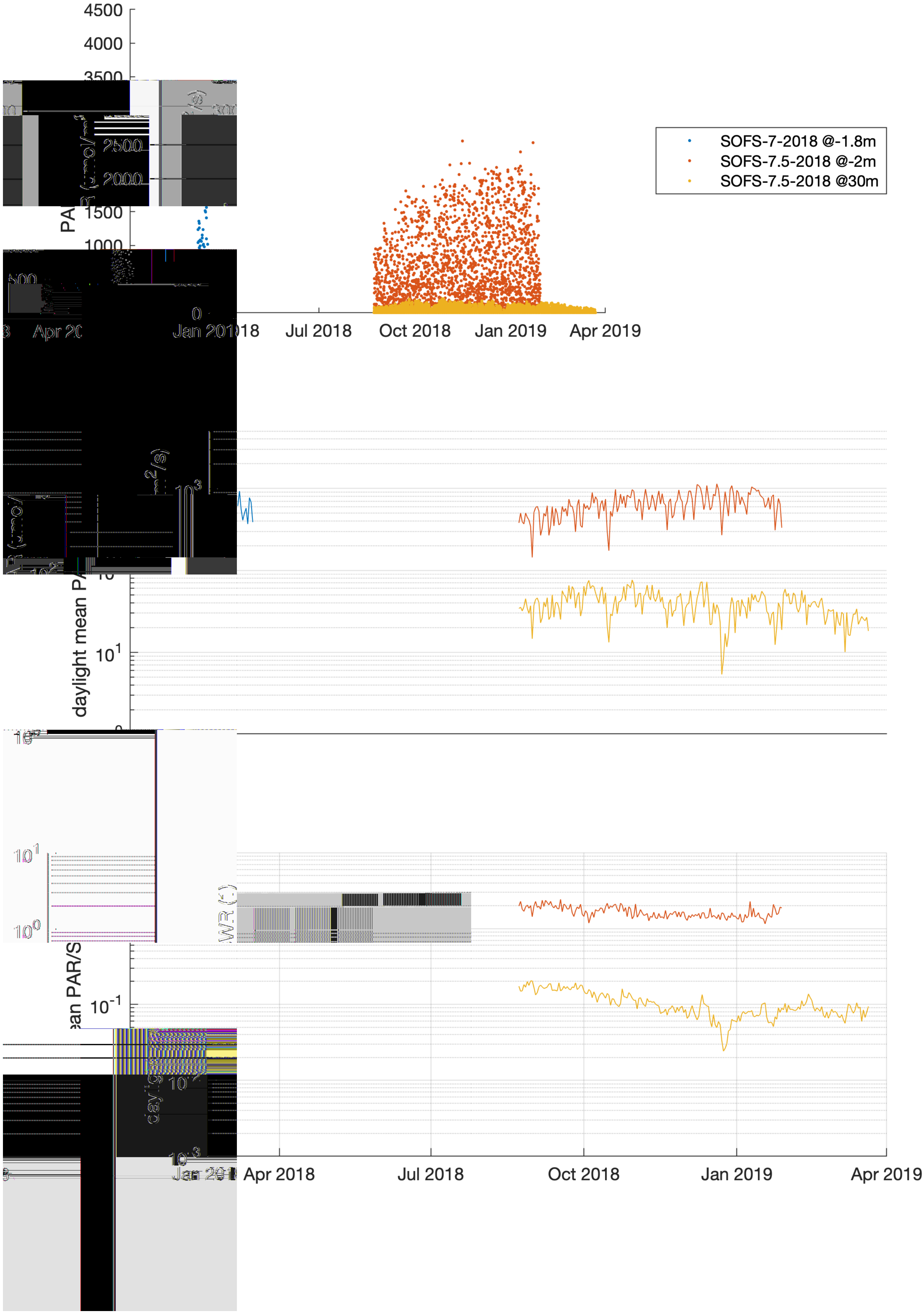

4500
4000
1500
1000
500
0
Mar
Apr
May
Jun
Jul
2016
FluxPulse-1-2016 @-1.8m


daylight mean PAR (umol/m^2/s)
10^3
10^2
10^1


10^-1
Apr
May
Jun
Jul
2016



SOFS-6-2017 @-1.8m
3000
2500
2000
1500
1000
500
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
2017
daylight mean PAR (umol/m^2/s)
10^3
10^1
10^0
daylight mean PAR/SWR (1)
10^1
10^0
10^-1
10^-2
10^-3
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
2017

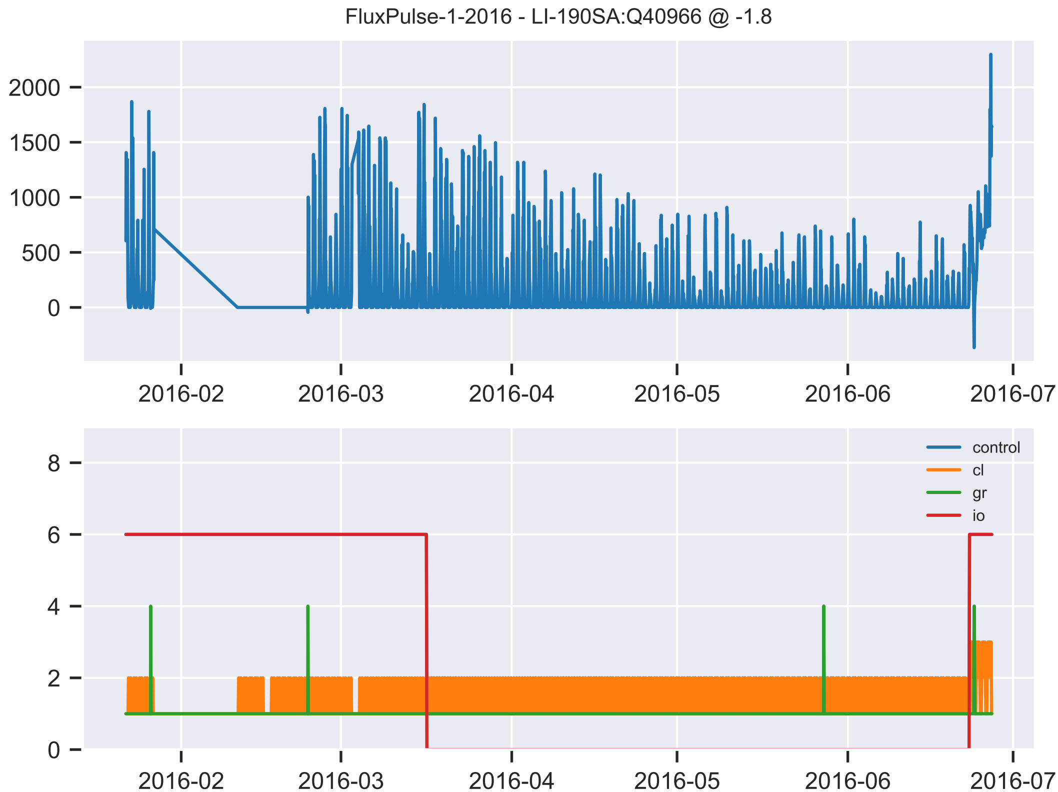


4500
4000
1500
1000
SOFS-7-2018 @-1.8m
SOFS-7.5-2018 @-2m
SOFS-7.5-2018 @30m
Jul 2018
Oct 2018
Jan 2019
Apr 2019
daylight mean PA
Apr 2018
Jul 2018
Oct 2018
Jan 2019
Apr 2019

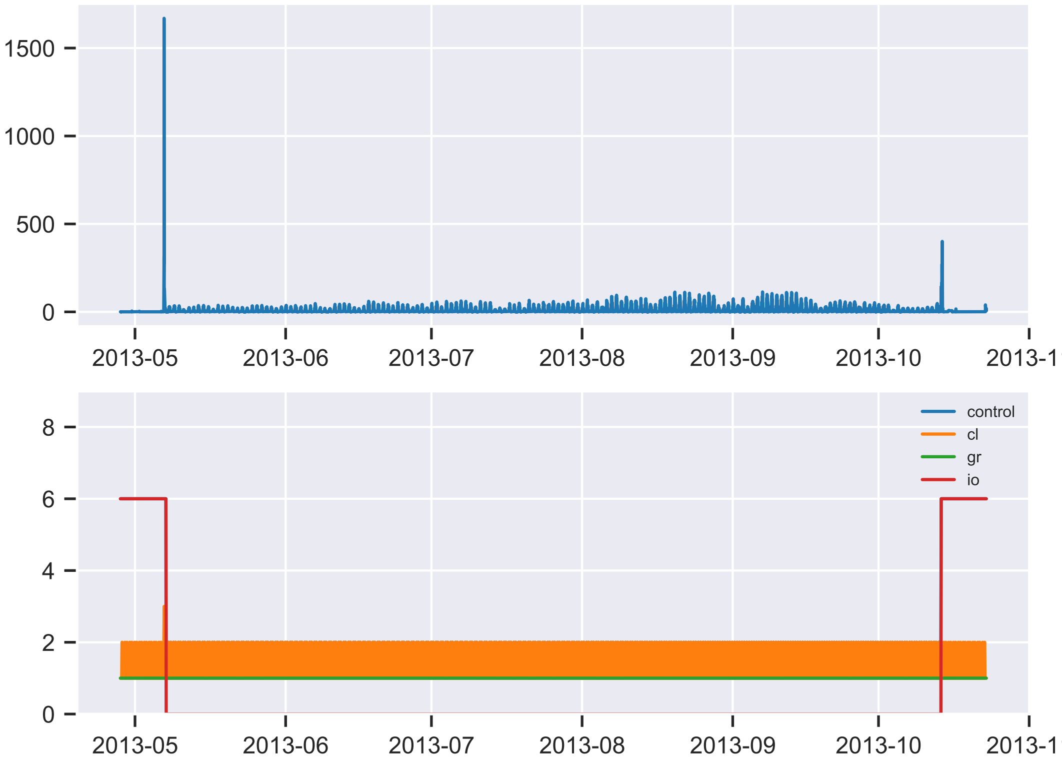
8 QC flag plots

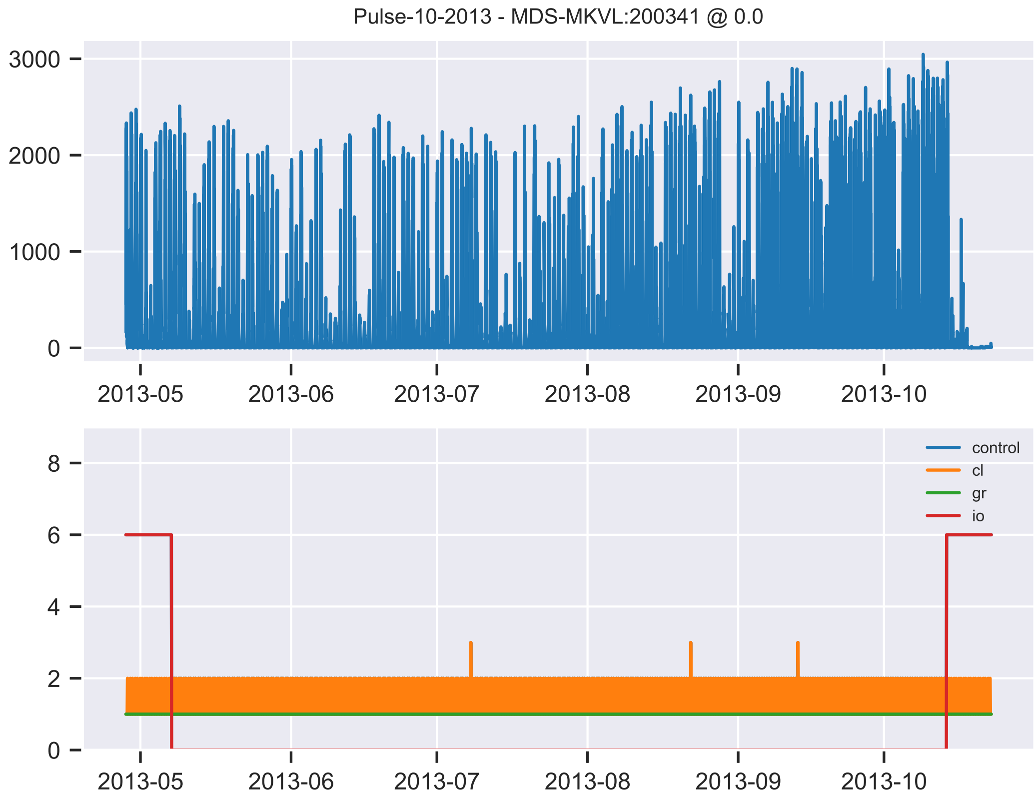
Plots of data, top panel, RAW data, bottom QC flags,

- control – overall QC flag (max of all flags)
- cl – climatology test result
- io – in/out of water flag
- gr – global range test result
- man – manual QC flag

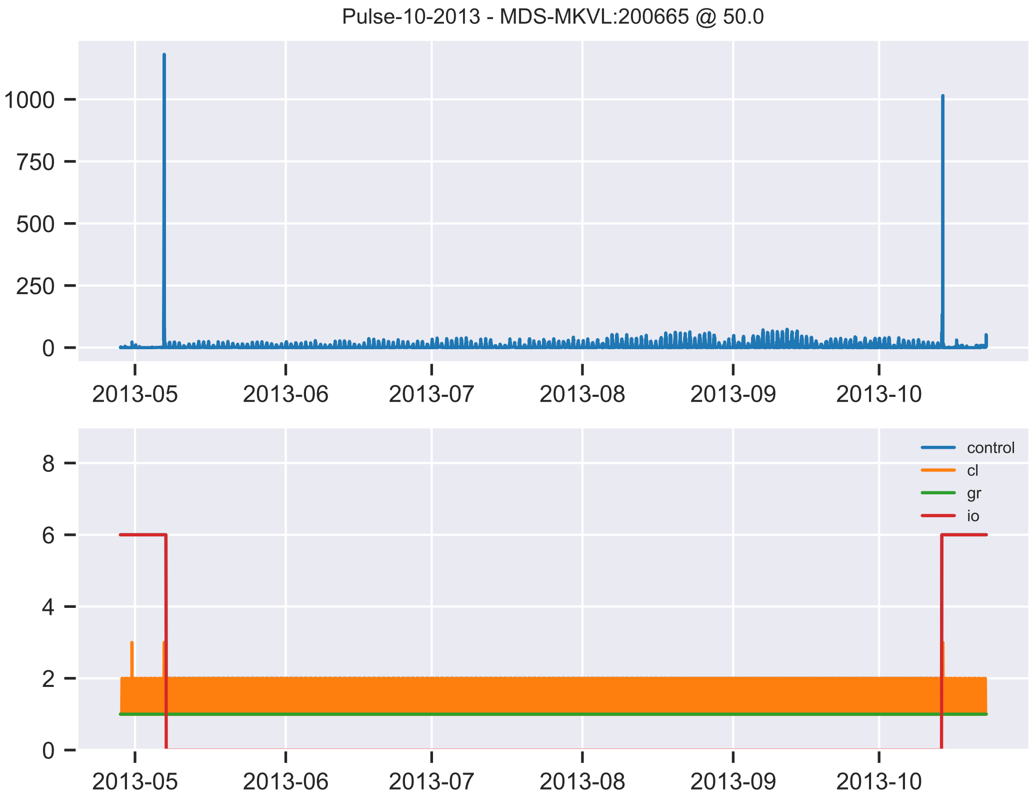

FluxPulse-1-2016 - LI-190SA:Q40966 @ -1.8
2000
1500
1000
500
0
2016-02
2016-03
2016-04
2016-05
2016-06
2016-07
8
6
4
2
0
control
cl
gr
io

Pulse-10-2013 - DEFI-L:082V023 @ 49.0

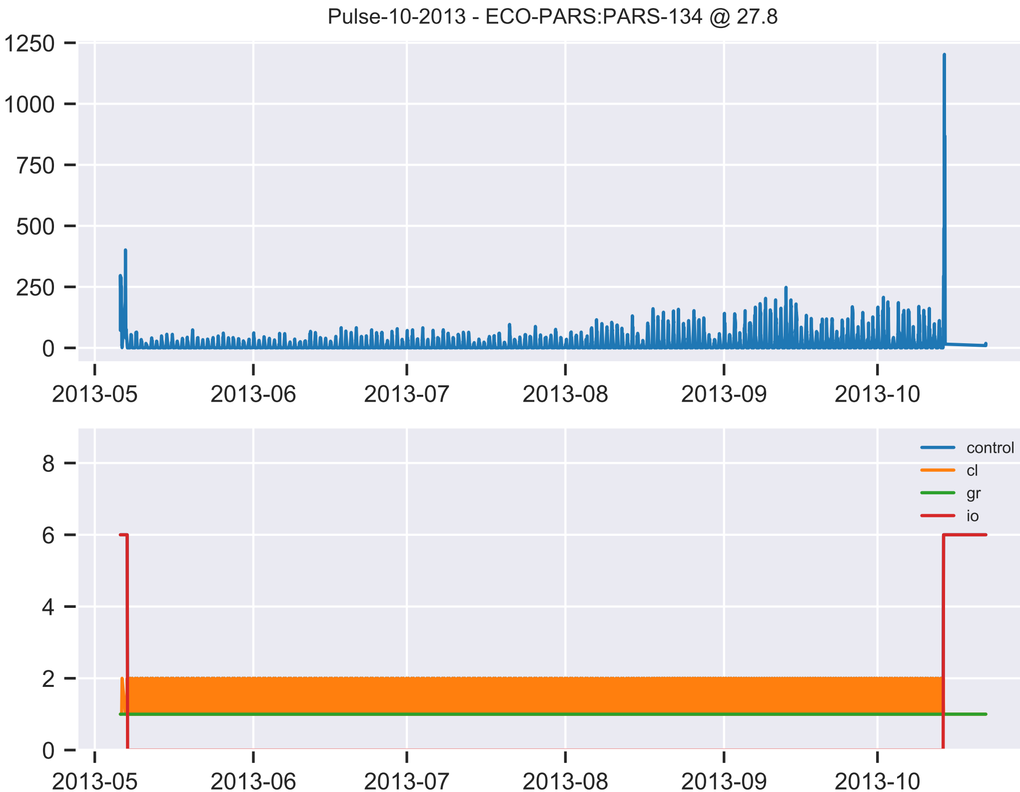




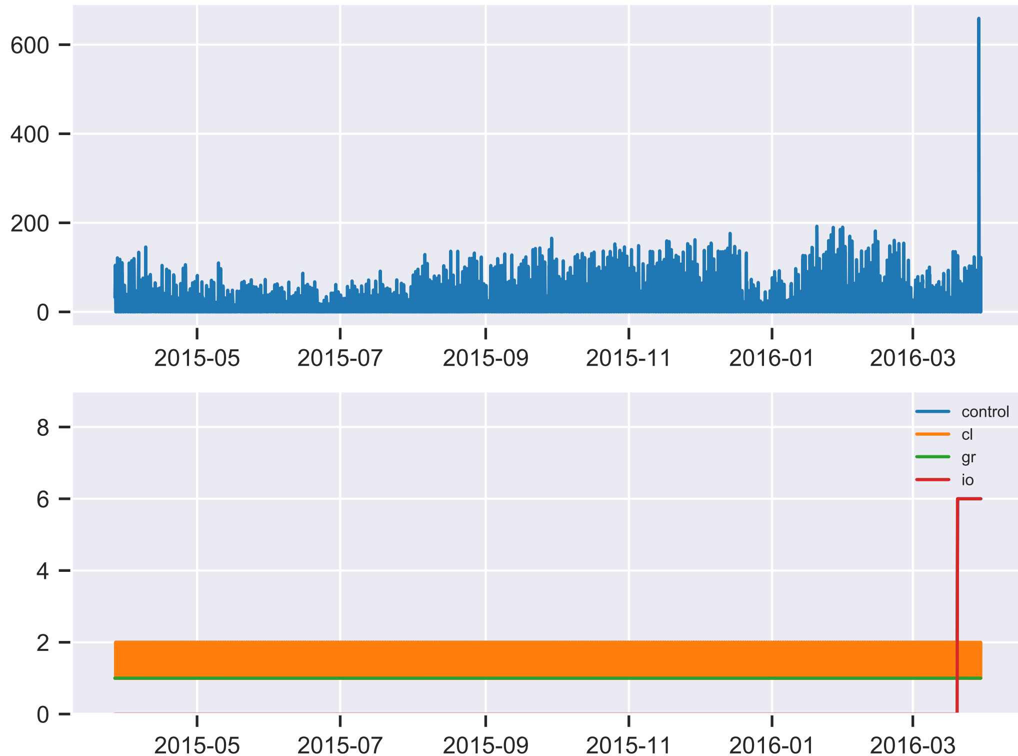
Pulse-10-2013 - MDS-MKVL:200341 @ 0.0
3000
2000
1000
0
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10
8
6
4
2
0
control
cl
gr
io
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10

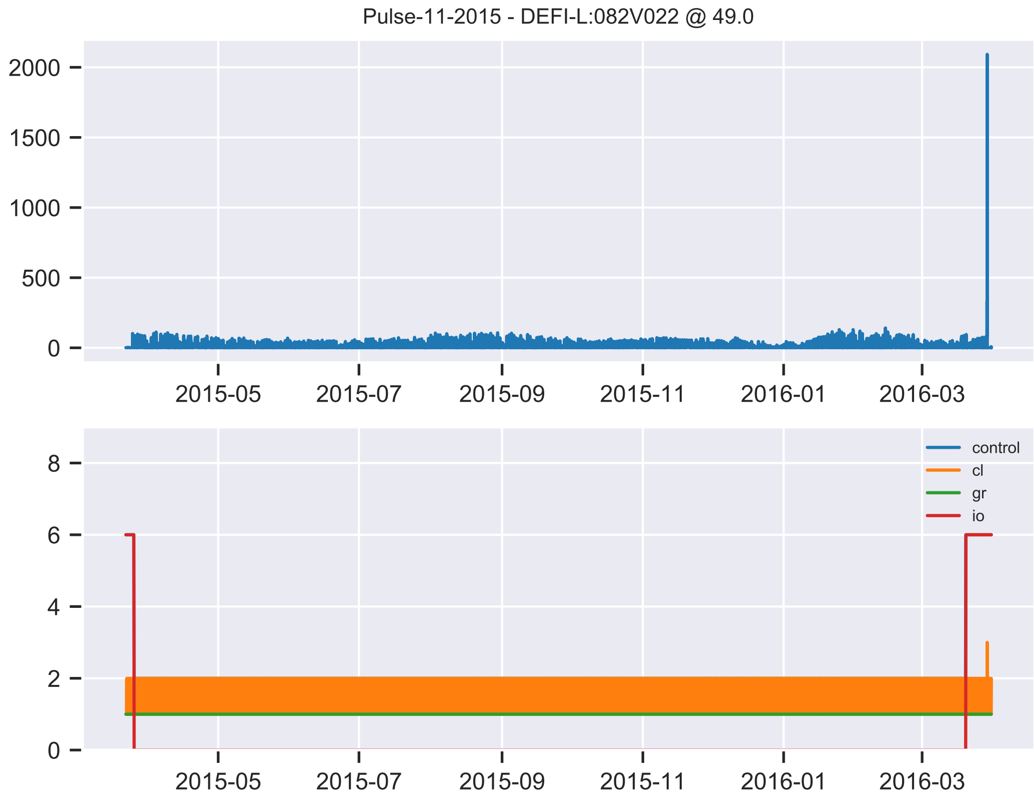


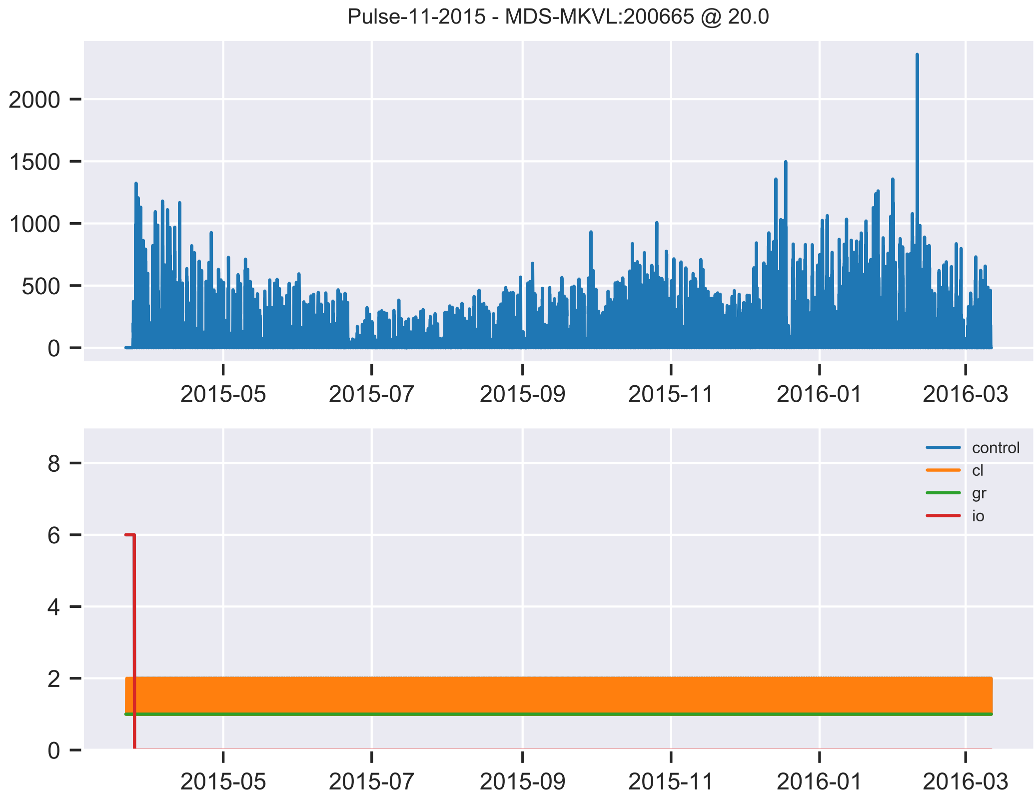
Pulse-10-2013 - MDS-MKVL:200665 @ 50.0
1000
750
500
250
0
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10
8
6
4
2
0
control
cl
gr
io
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10


Pulse-10-2013 - ECO-PARS:PARS-134 @ 27.8
1250
1000
750
500
250
0
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10
8
6
4
2
0
control
cl
gr
io

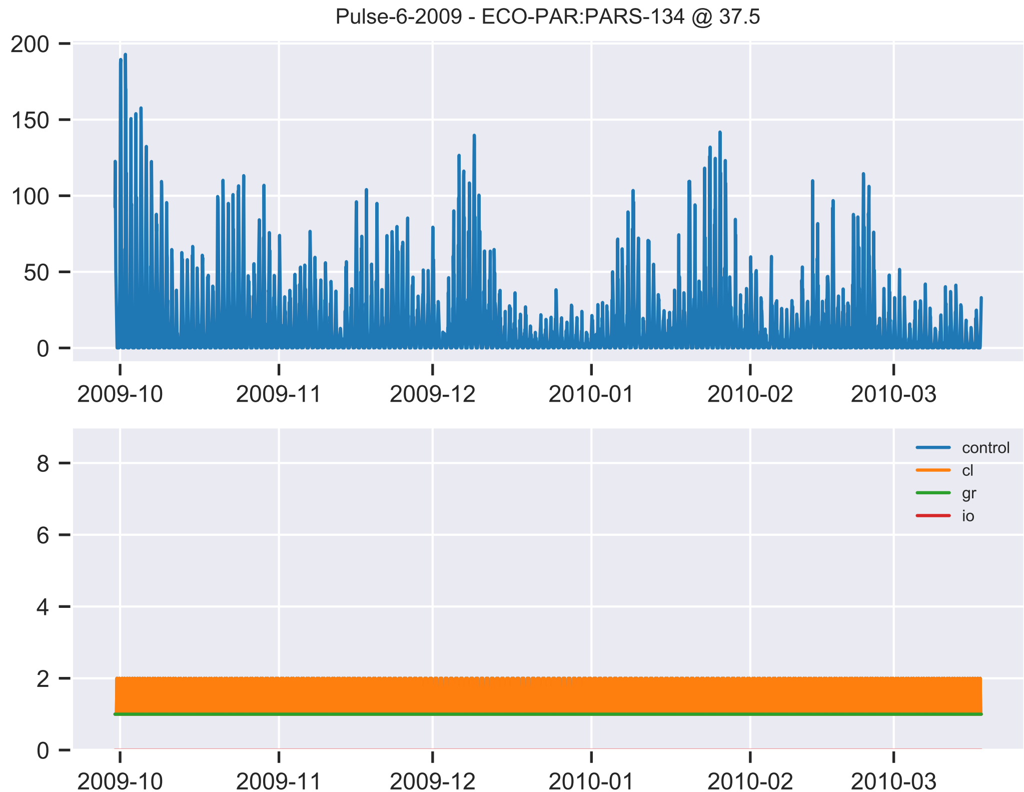
Pulse-11-2015 - ECO-PAR:PARS-134 @ 28.0

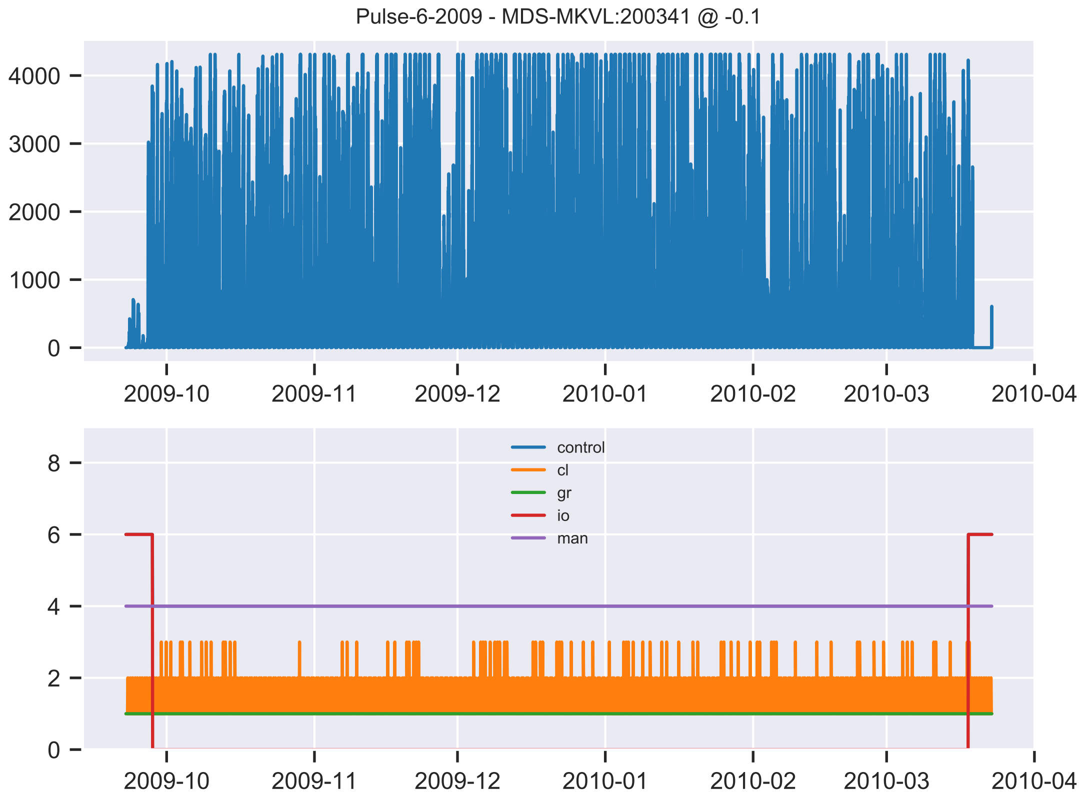



Pulse-11-2015 - DEFI-L:082V022 @ 49.0
2000
1500
1000
500
0
2015-05
2015-07
2015-09
2015-11
2016-01
2016-03
8
6
4
2
0
control
cl
gr
io
2015-05
2015-07
2015-09
2015-11
2016-01
2016-03



Pulse-11-2015 - MDS-MKVL:200665 @ 20.0
2000
1500
1000
500
0
2015-05
2015-07
2015-09
2015-11
2016-01
2016-03
8
6
4
2
0
control
cl
gr
io
2015-05
2015-07
2015-09
2015-11
2016-01
2016-03

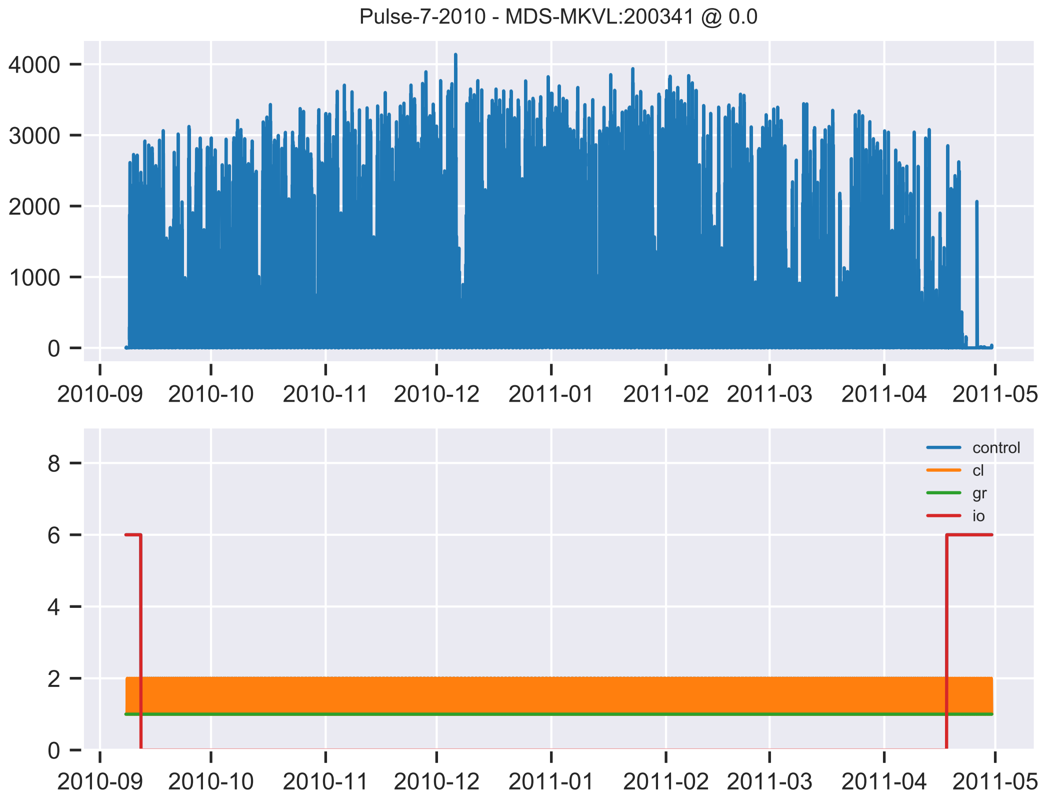

Pulse-6-2009 - ECO-PAR:PARS-134 @ 37.5
200
150
100
50
0
2009-10
2009-11
2009-12
2010-01
2010-02
2010-03
8
6
4
2
0
control
cl
gr
io
2009-10
2009-11
2009-12
2010-01
2010-02
2010-03



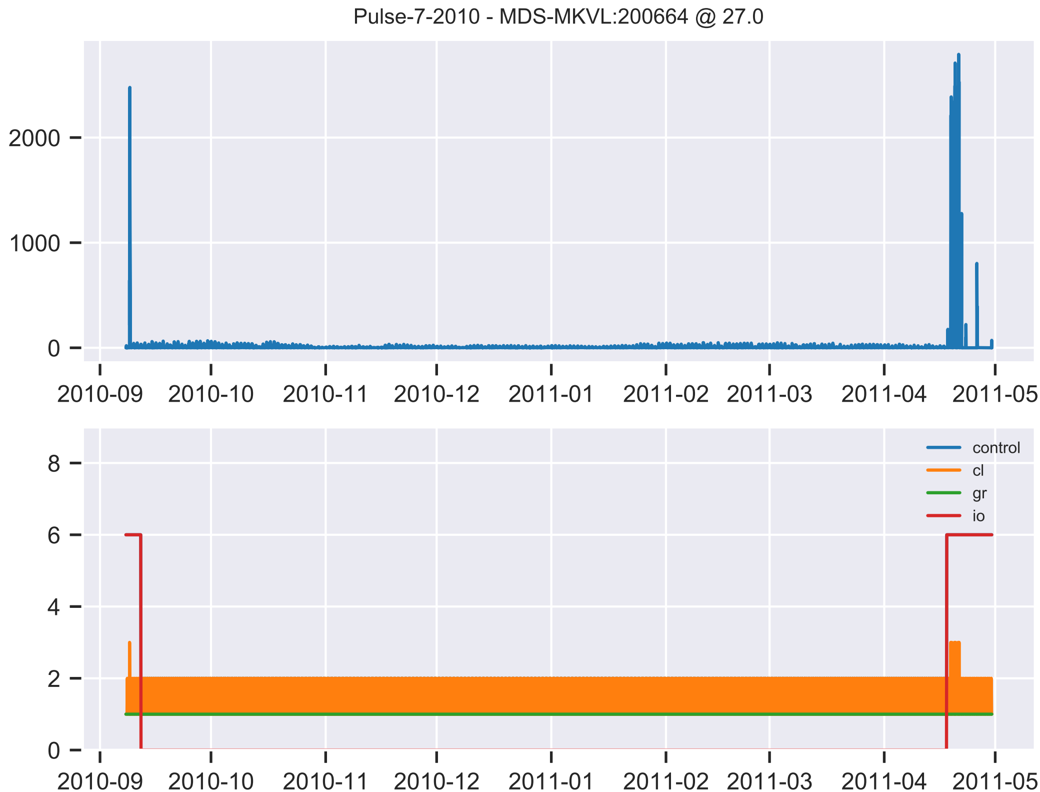
Pulse-6-2009 - MDS-MKVL:200341 @ -0.1
4000
3000
2000
1000
0
2009-10
2009-11
2009-12
2010-01
2010-02
2010-03
2010-04
8
6
4
2
0
control
cl
gr
io
man

Pulse-6-2009 - MDS-MKVL:200664 @ 27.0
3000
2000
1000
0
2009-10
2009-11
2009-12
2010-01
2010-02
2010-03
2010-04
8
6
4
2
0
control
cl
gr
io
man
2009-10
2009-11
2009-12
2010-01
2010-02
2010-03
2010-04

Pulse-6-2009 - MDS-MKVL:200665 @ 50.0
3000
2000
1000
0
2009-10
2009-11
2009-12
2010-01
2010-02
2010-03
2010-04
8
6
4
2
0
control
cl
gr
io

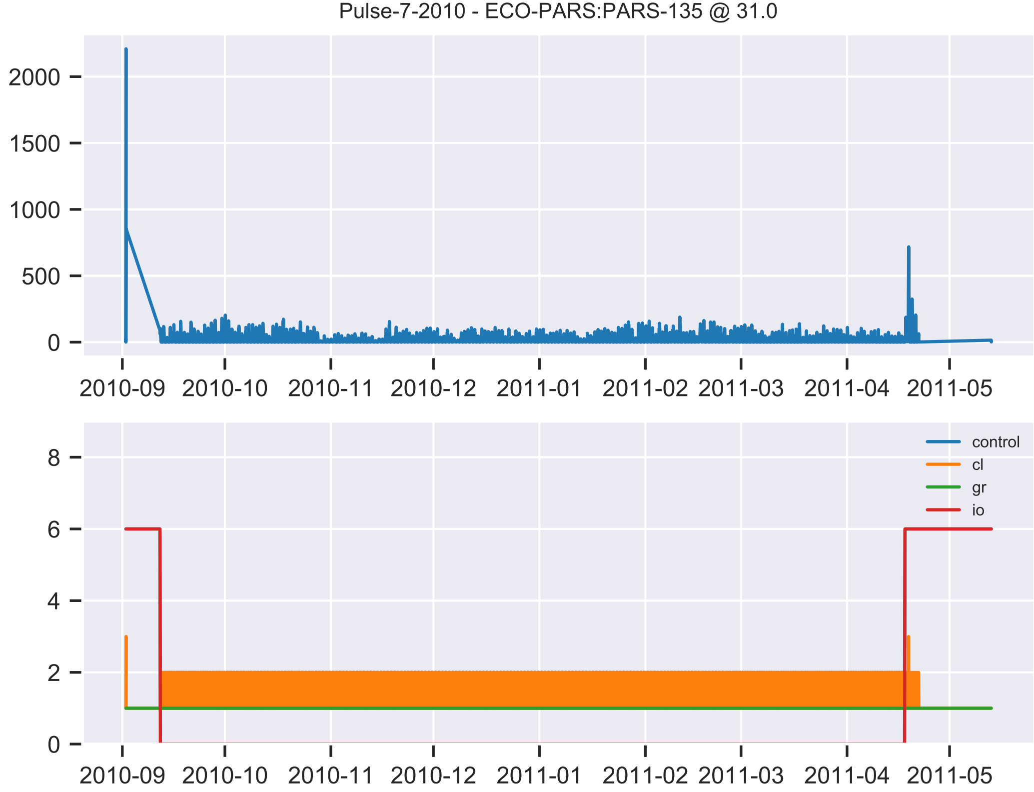


Pulse-7-2010 - MDS-MKVL:200341 @ 0.0
4000
3000
2000
1000
0
2010-09
2010-10
2010-11
2010-12
2011-01
2011-02
2011-03
2011-04
2011-05
8
6
4
2
0
control
cl
gr
io

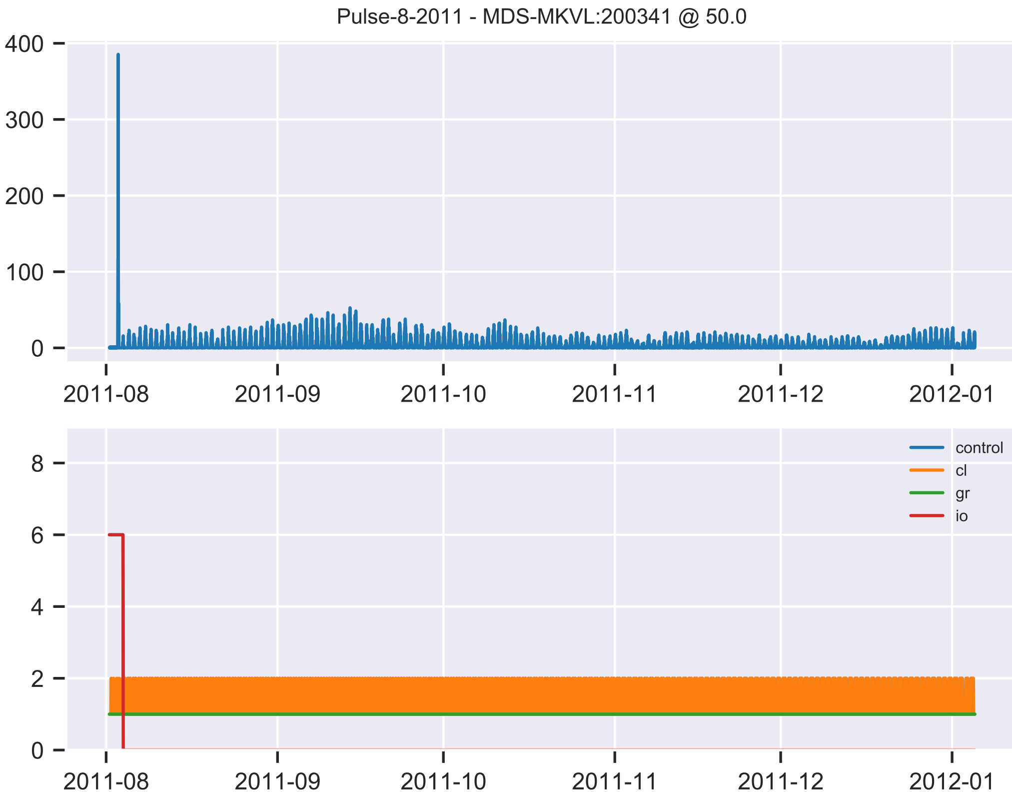


Pulse-7-2010 - MDS-MKVL:200664 @ 27.0
2000
1000
0
2010-09
2010-10
2010-11
2010-12
2011-01
2011-02
2011-03
2011-04
2011-05
8
6
4
2
0
control
cl
gr
io

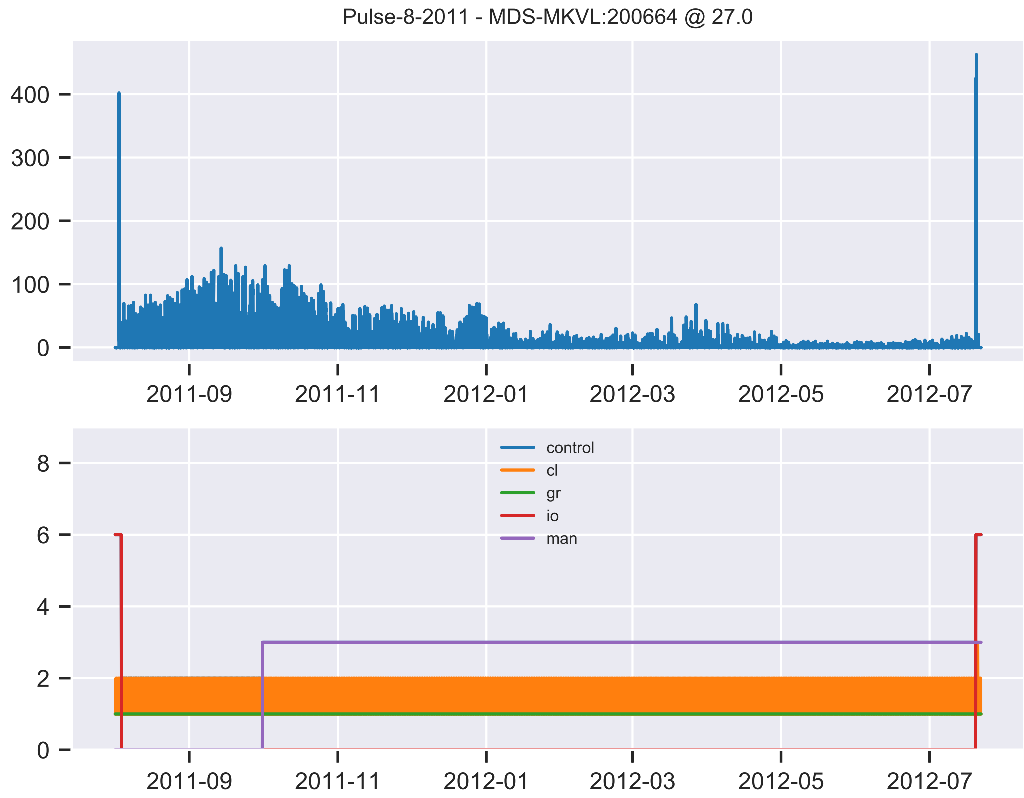

Pulse-7-2010 - MDS-MKVL:200665 @ 50.0
2000
1500
1000
500
0
2010-09
2010-10
2010-11
2010-12
2011-01
2011-02
2011-03
2011-04
2011-05
2011-06
2011-07
control
cl
gr
io
man
8
6
4
2
0
2010-09
2010-10
2010-11
2010-12
2011-01
2011-02
2011-03
2011-04
2011-05
2011-06
2011-07



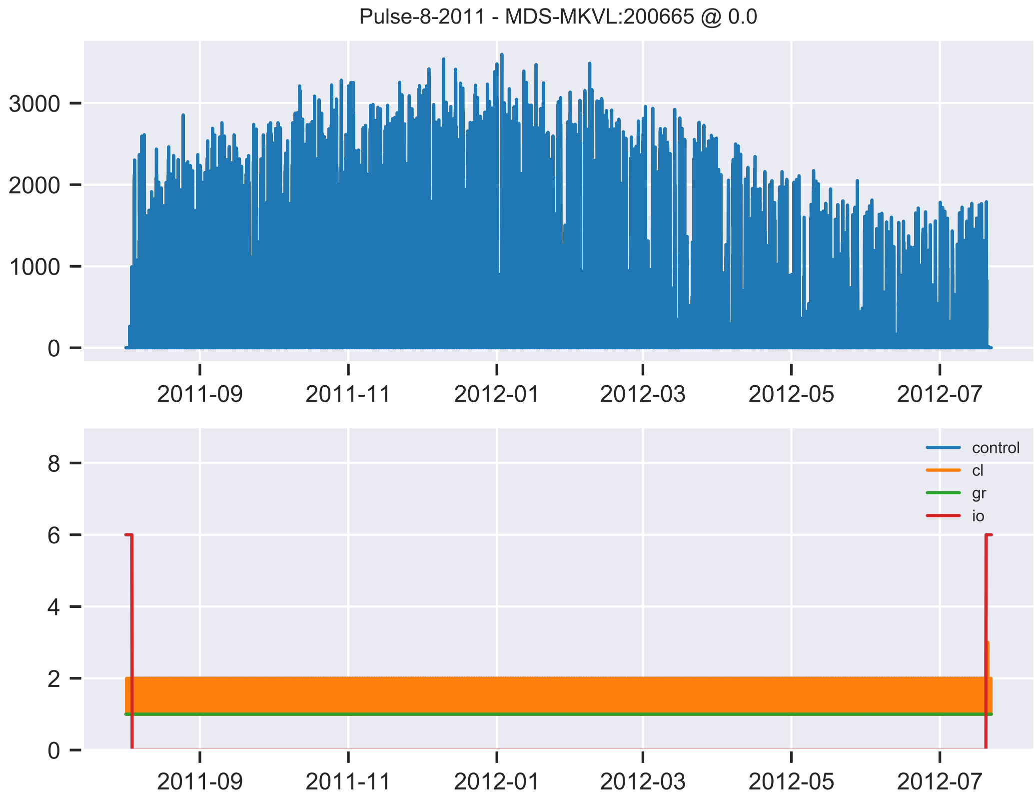
Pulse-7-2010 - ECO-PARS:PARS-135 @ 31.0
2000
1500
1000
500
0
2010-09
2010-10
2010-11
2010-12
2011-01
2011-02
2011-03
2011-04
2011-05
8
6
4
2
0
control
cl
gr
io

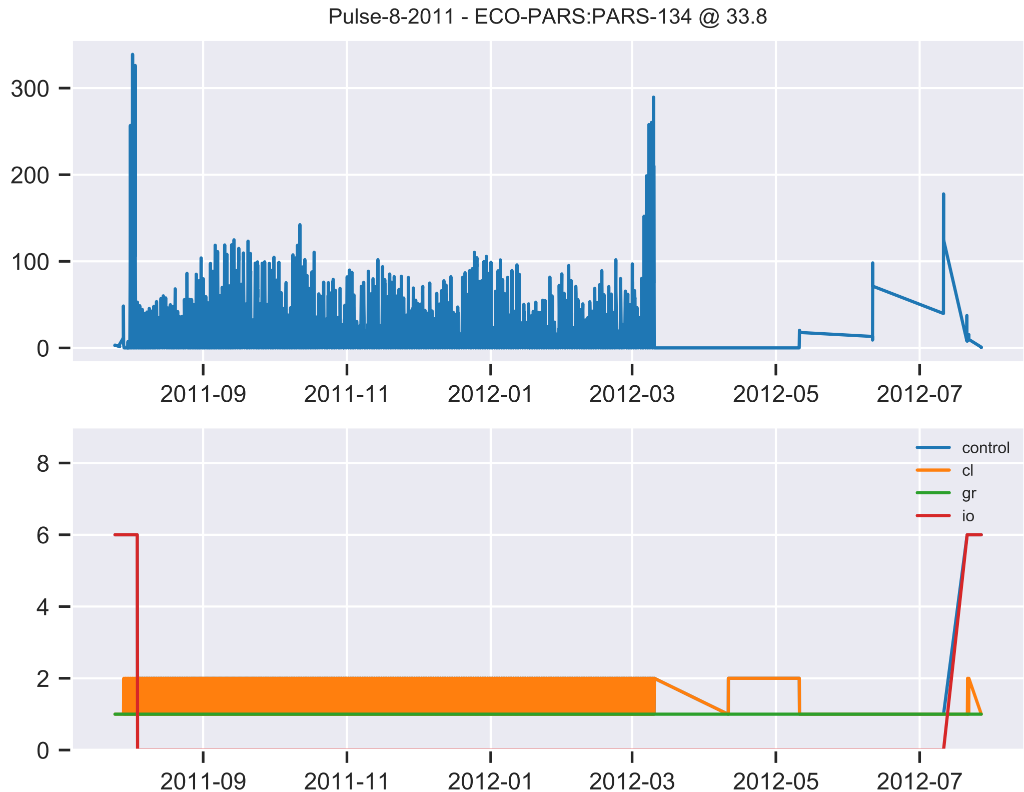


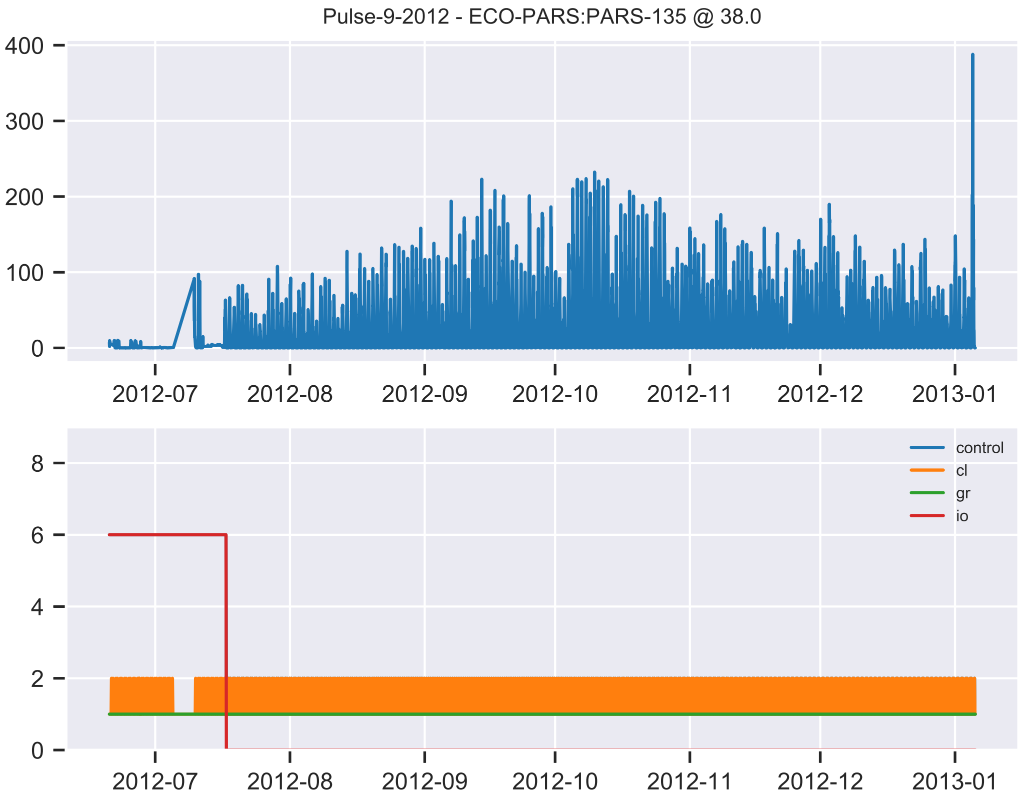
Pulse-8-2011 - MDS-MKVL:200341 @ 50.0
400
300
200
100
0
2011-08
2011-09
2011-10
2011-11
2011-12
2012-01
8
6
4
2
0
control
cl
gr
io



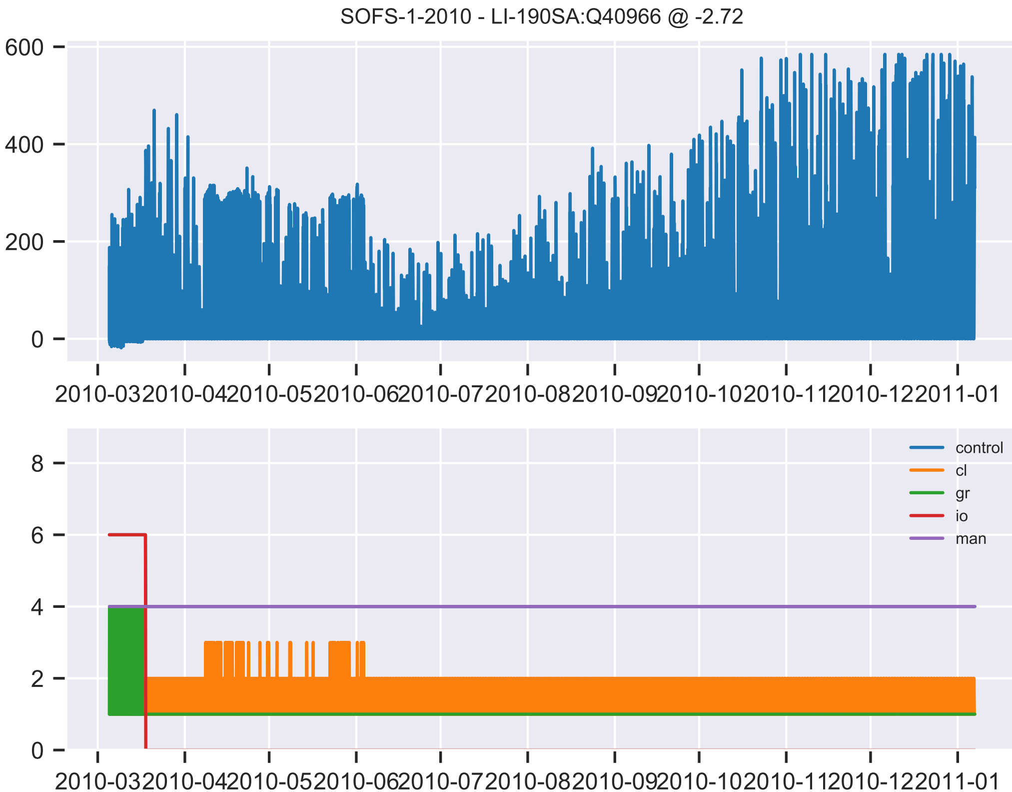
Pulse-8-2011 - MDS-MKVL:200664 @ 27.0
400
300
200
100
0
2011-09
2011-11
2012-01
2012-03
2012-05
2012-07
8
6
4
2
0
control
cl
gr
io
man
2011-09
2011-11
2012-01
2012-03
2012-05
2012-07


Pulse-8-2011 - MDS-MKVL:200665 @ 0.0
3000
2000
1000
0
2011-09
2011-11
2012-01
2012-03
2012-05
2012-07
8
6
4
2
0
control
cl
gr
io
2011-09
2011-11
2012-01
2012-03
2012-05
2012-07

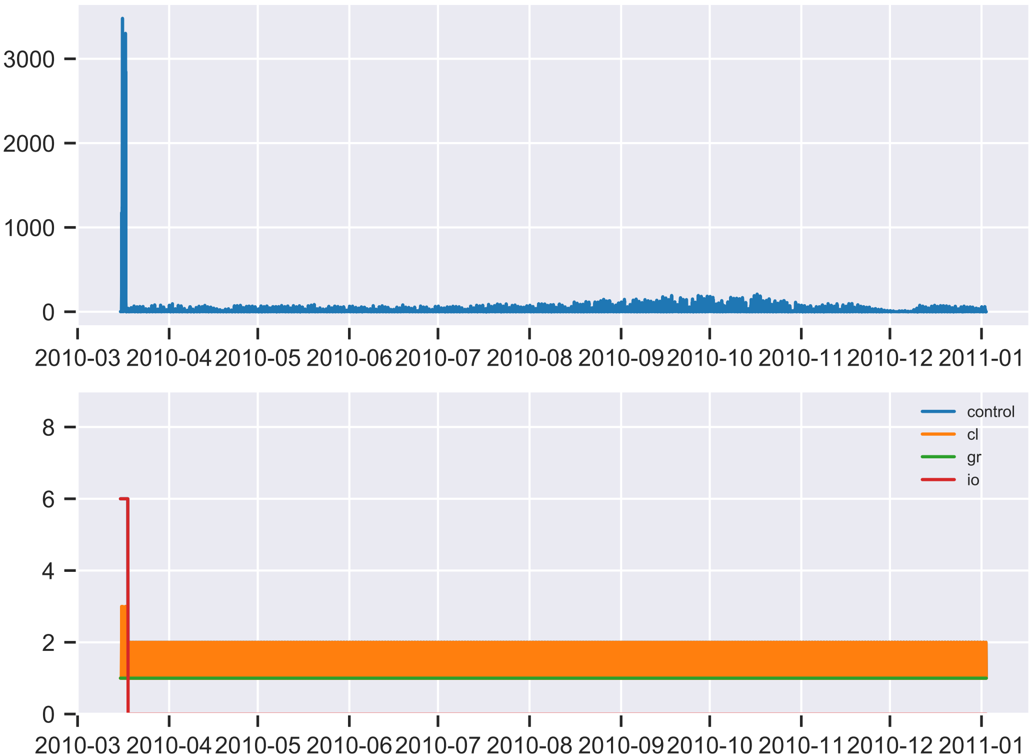

Pulse-8-2011 - ECO-PARS:PARS-134 @ 33.8
300
200
100
0
2011-09
2011-11
2012-01
2012-03
2012-05
2012-07
8
6
4
2
0
control
cl
gr
io
2011-09
2011-11
2012-01
2012-03
2012-05
2012-07



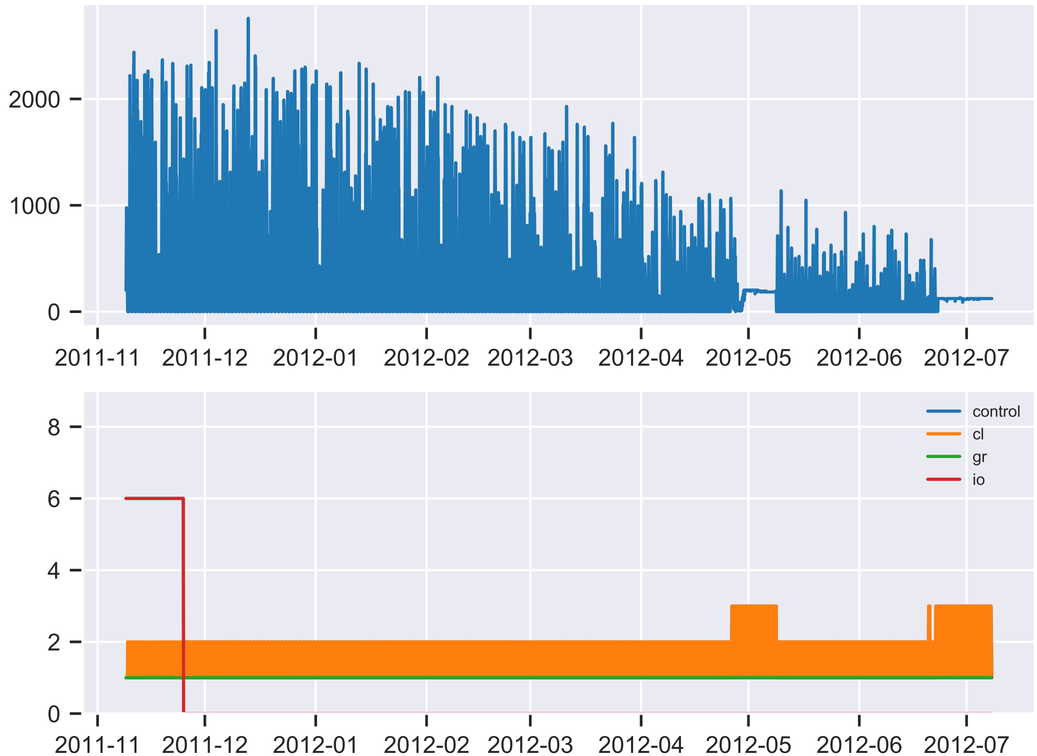
Pulse-9-2012 - ECO-PARS:PARS-135 @ 38.0
400
300
200
100
0
2012-07
2012-08
2012-09
2012-10
2012-11
2012-12
2013-01
8
6
4
2
0
control
cl
gr
io


SOFS-1-2010 - LI-190SA:Q40966 @ -2.72
600
400
200
0
2010-03
2010-04
2010-05
2010-06
2010-07
2010-08
2010-09
2010-10
2010-11
2010-12
2011-01
8
6
4
2
0
control
cl
gr
io
man

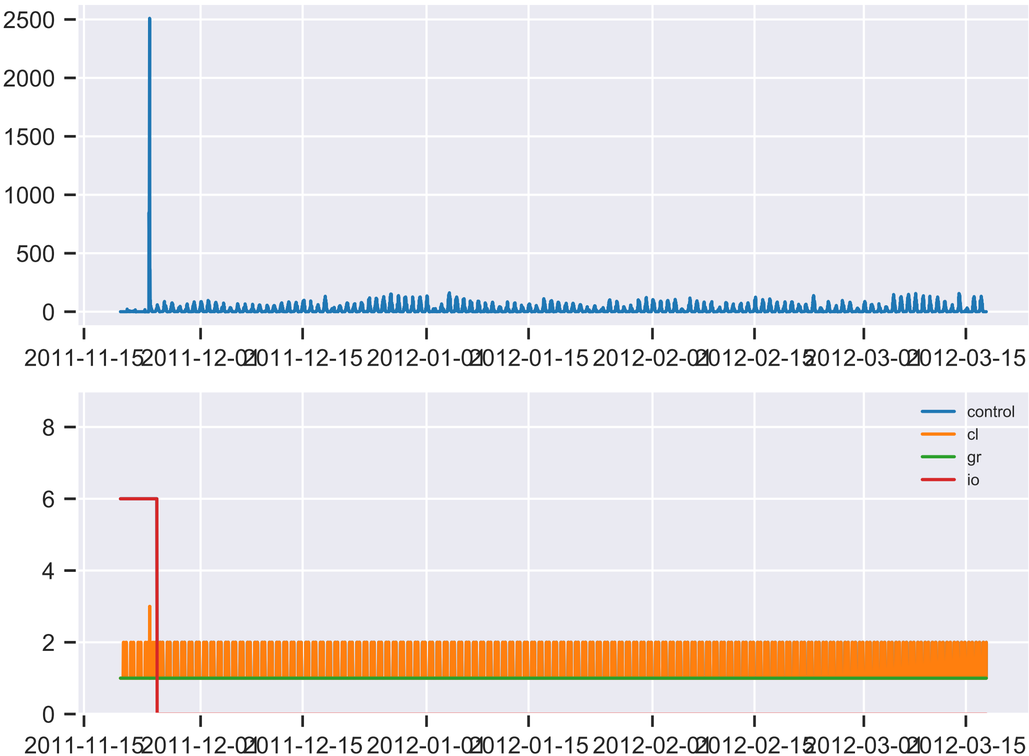
SOFS-1-2010 - MDS-MKVL:201318 @ 40.0



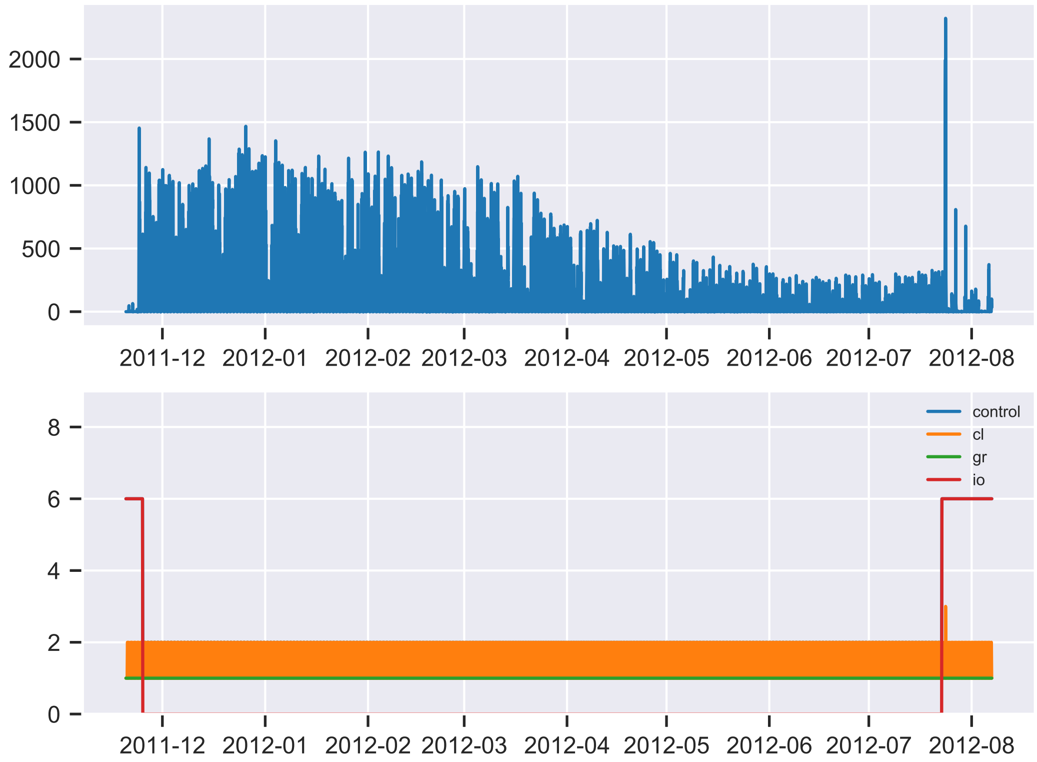
SOFS-2-2011 - LI-190SA:Q40966 @ -3.0

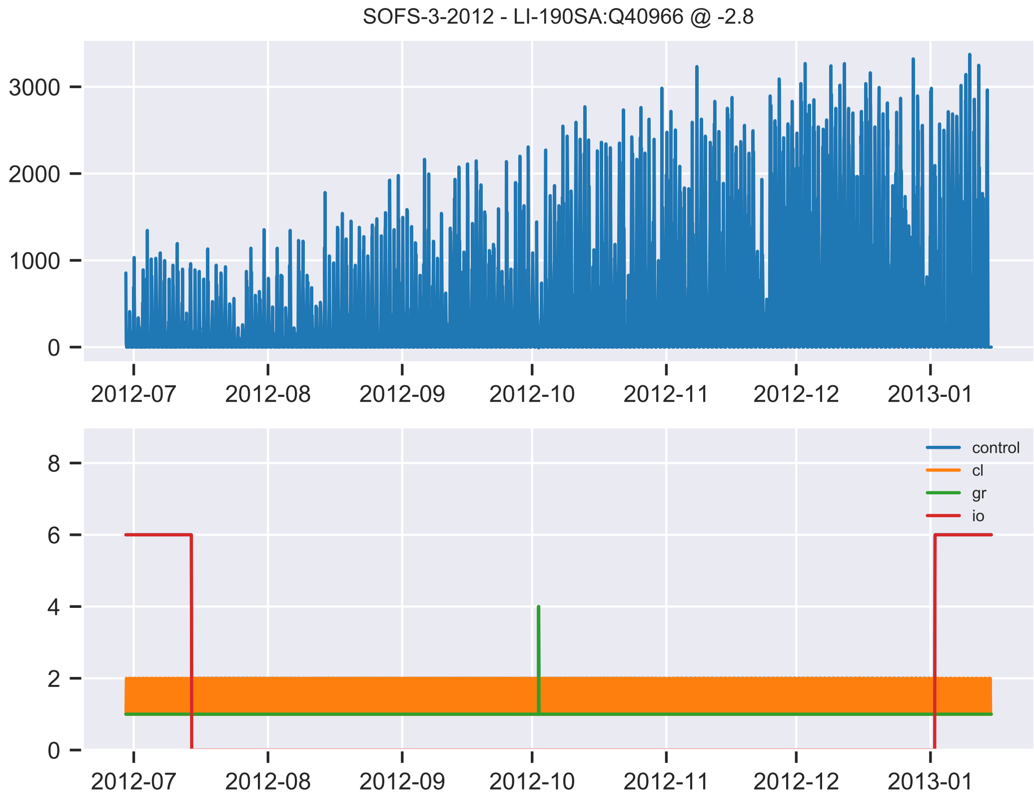


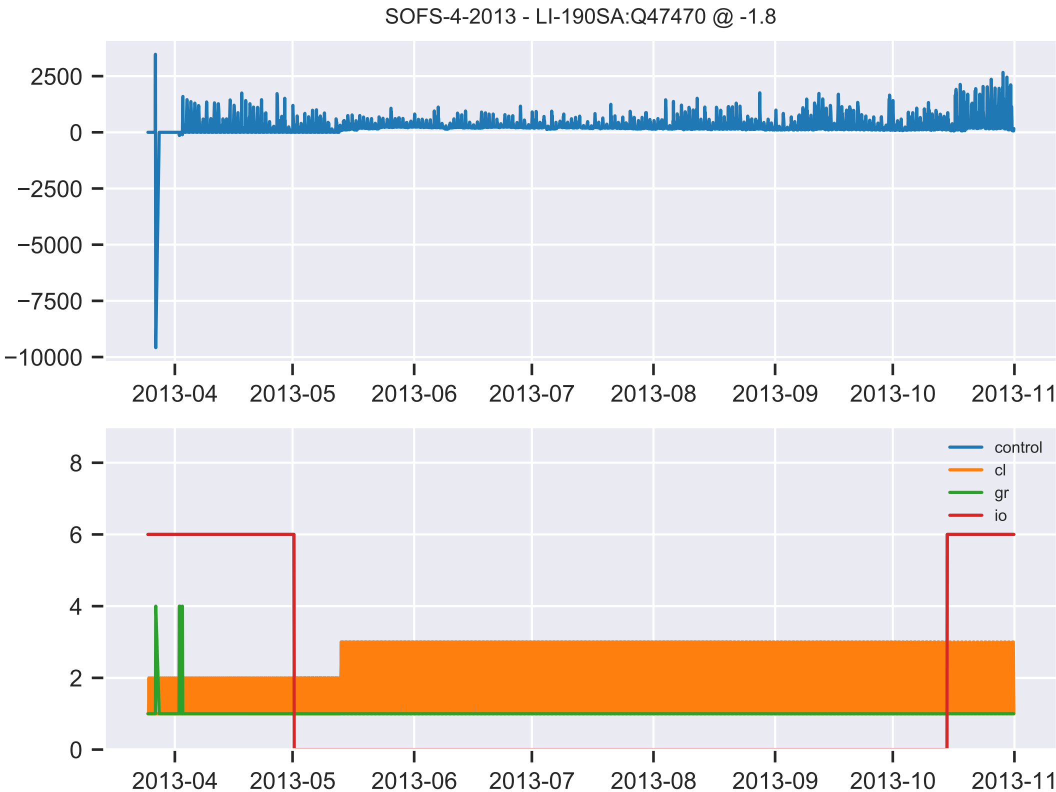
SOFS-2-2011 - MDS-MKVL:201318 @ 40.0



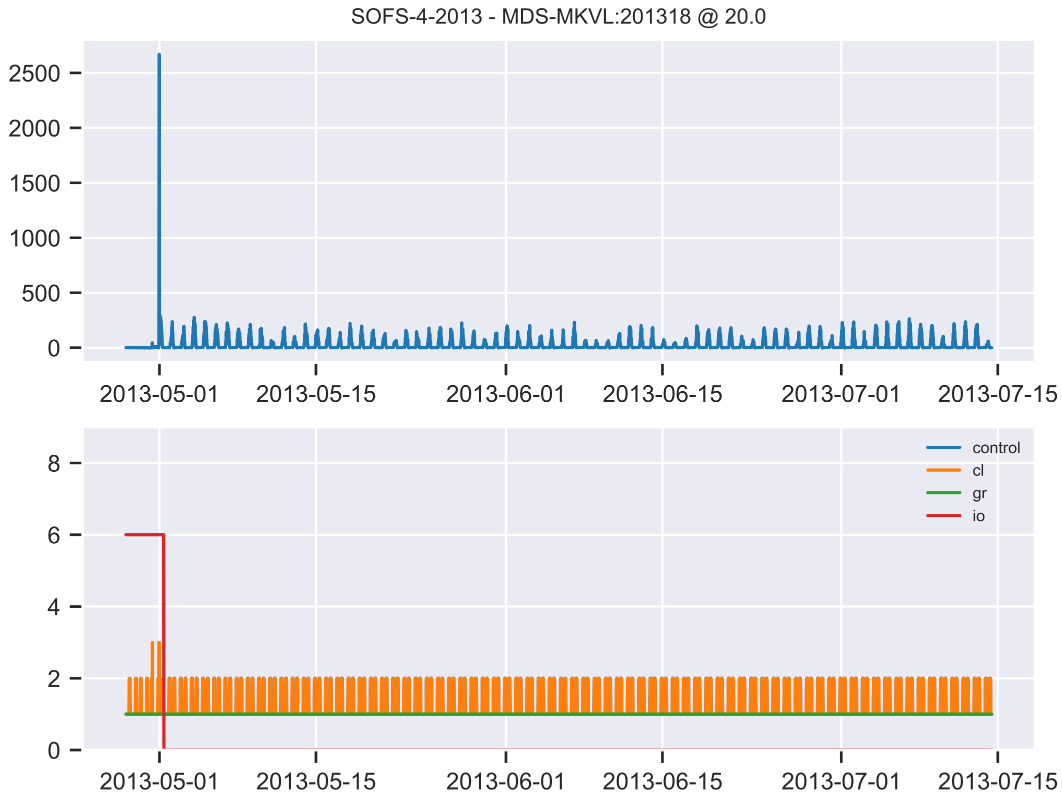
SOFS-2-2011 - MDS-MKVL:201319 @ 10.0

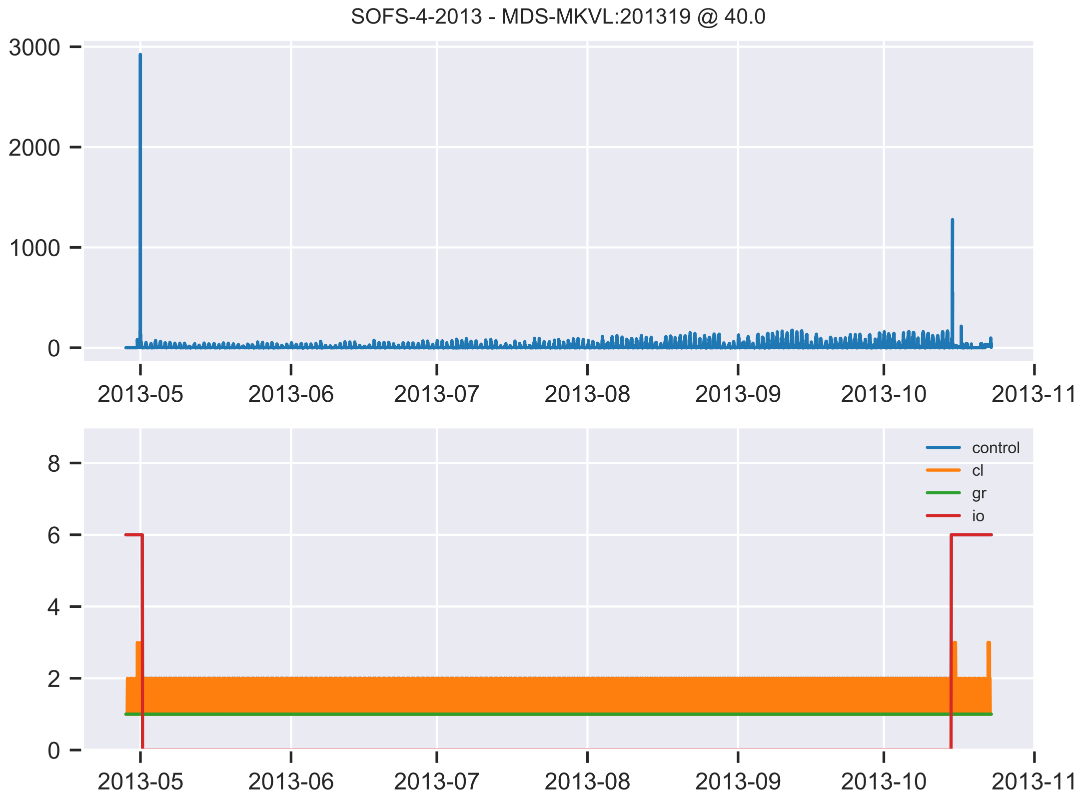



SOFS-3-2012 - LI-190SA:Q40966 @ -2.8
3000
2000
1000
0
2012-07
2012-08
2012-09
2012-10
2012-11
2012-12
2013-01
8
6
4
2
0
control
cl
gr
io
2012-07
2012-08
2012-09
2012-10
2012-11
2012-12
2013-01

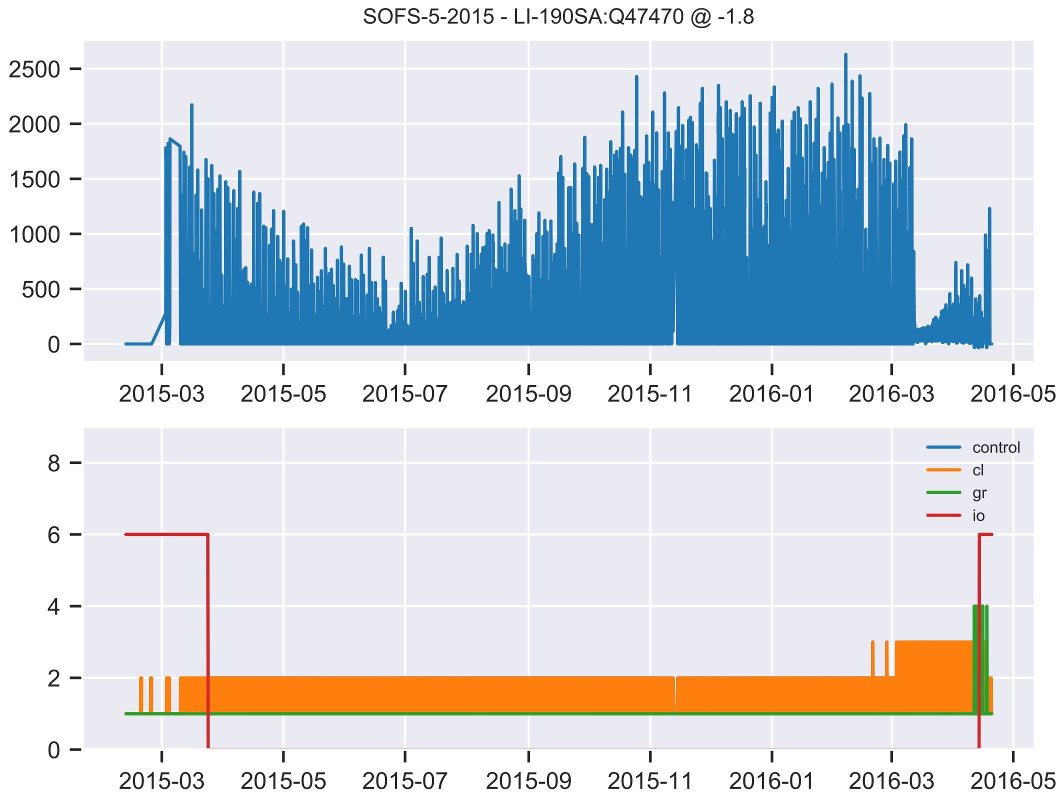


SOFS-4-2013 - LI-190SA:Q47470 @ -1.8
2500
0
−2500
−5000
−7500
−10000
2013-04
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10
2013-11
control
cl
gr
io
8
6
4
2
0

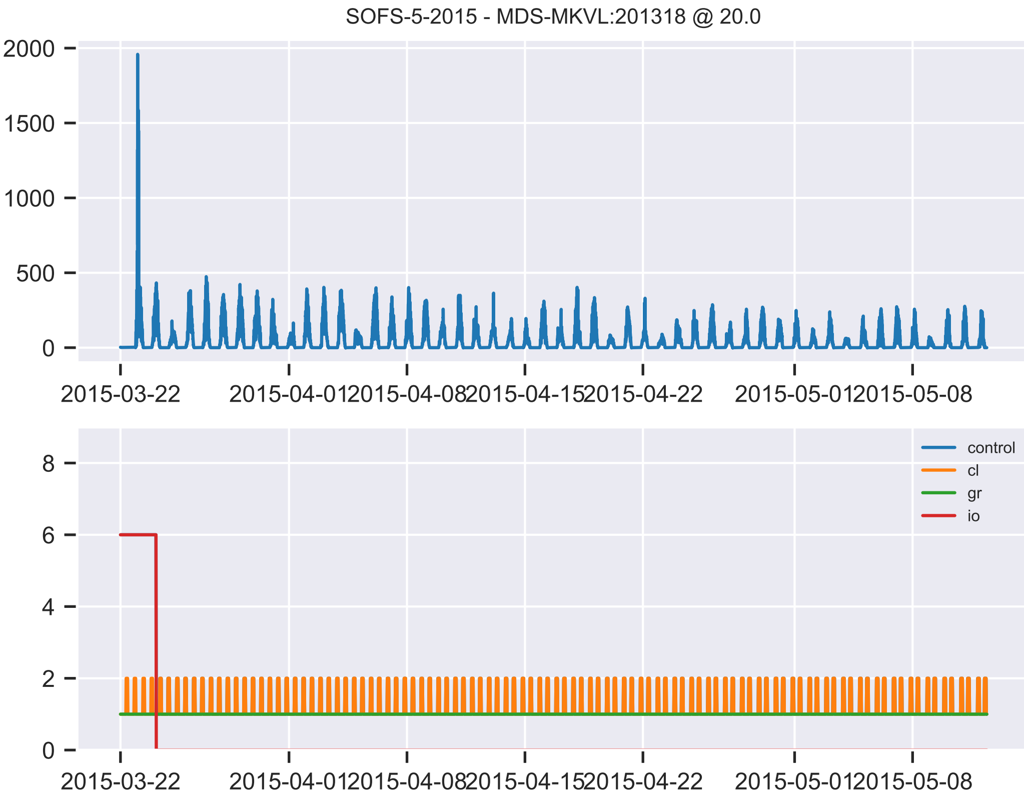

SOFS-4-2013 - MDS-MKVL:201318 @ 20.0
2500
2000
1500
1000
500
0
2013-05-01
2013-05-15
2013-06-01
2013-06-15
2013-07-01
2013-07-15
control
cl
gr
io
8
6
4
2
0
2013-05-01
2013-05-15
2013-06-01
2013-06-15
2013-07-01
2013-07-15

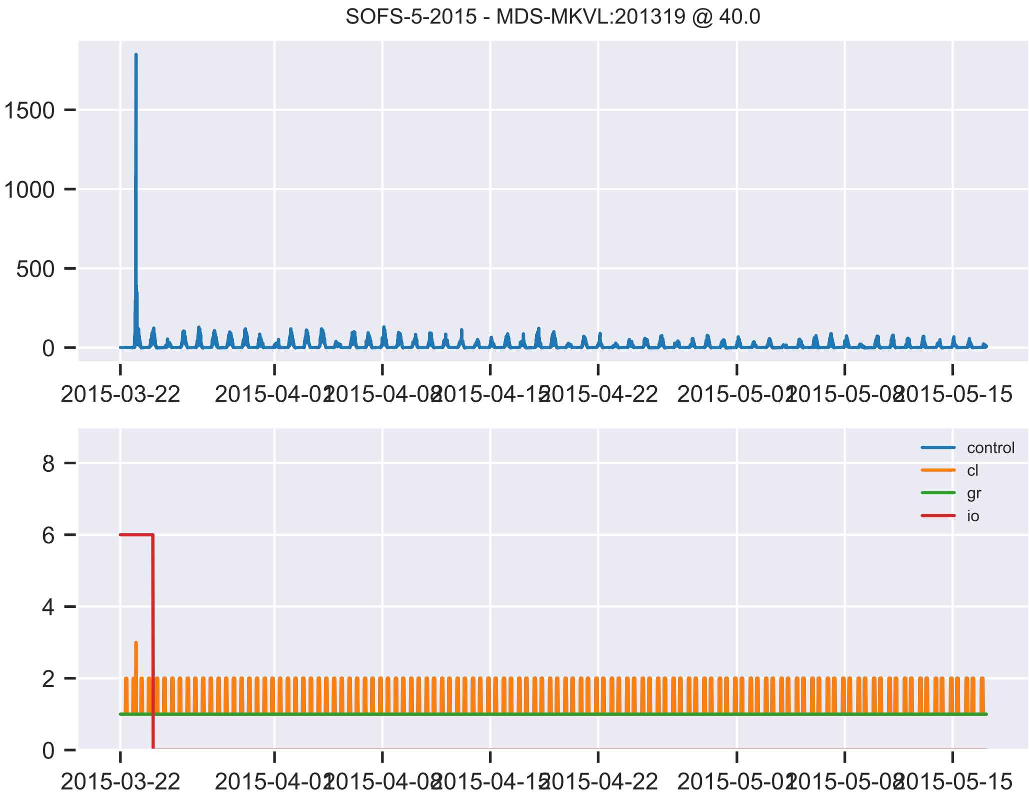


SOFS-4-2013 - MDS-MKVL:201319 @ 40.0
3000
2000
1000
0
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10
2013-11
8
6
4
2
0
control
cl
gr
io
2013-05
2013-06
2013-07
2013-08
2013-09
2013-10
2013-11

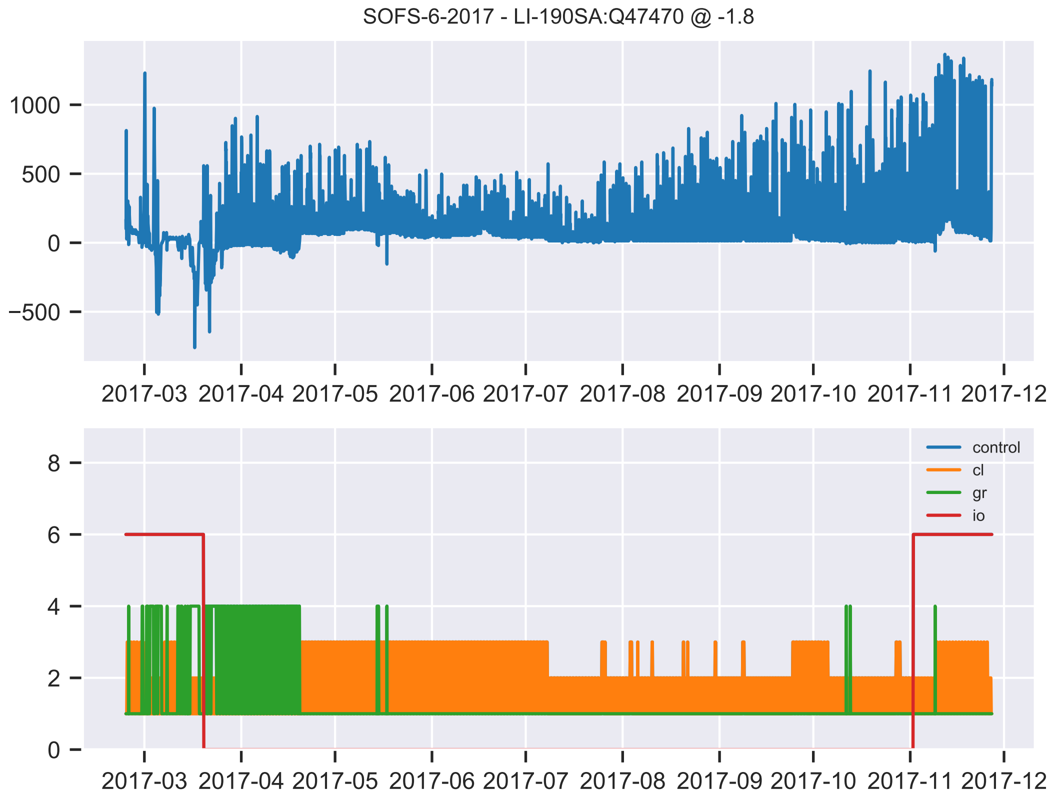


SOFS-5-2015 - LI-190SA:Q47470 @ -1.8
2500
2000
1500
1000
500
0
2015-03
2015-05
2015-07
2015-09
2015-11
2016-01
2016-03
2016-05
8
6
4
2
0
control
cl
gr
io

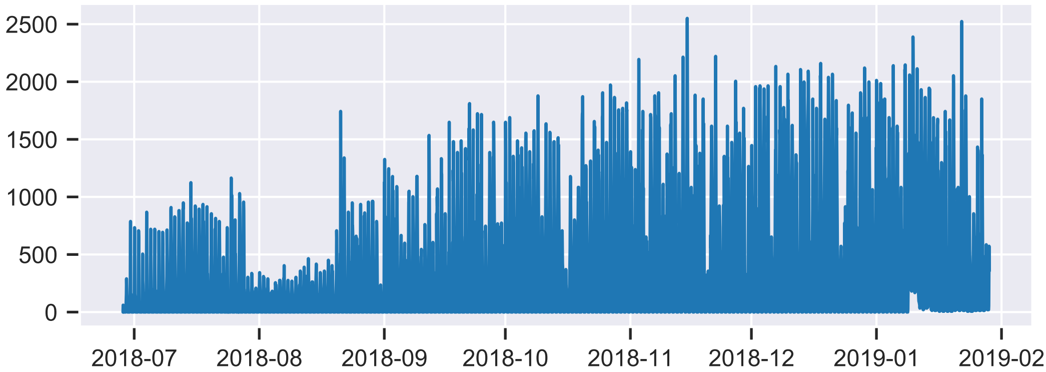

SOFS-5-2015 - MDS-MKVL:201318 @ 20.0
2000
1500
1000
500
0
2015-03-22
2015-04-01
2015-04-08
2015-04-15
2015-04-22
2015-05-01
2015-05-08
8
6
4
2
0
control
cl
gr
io

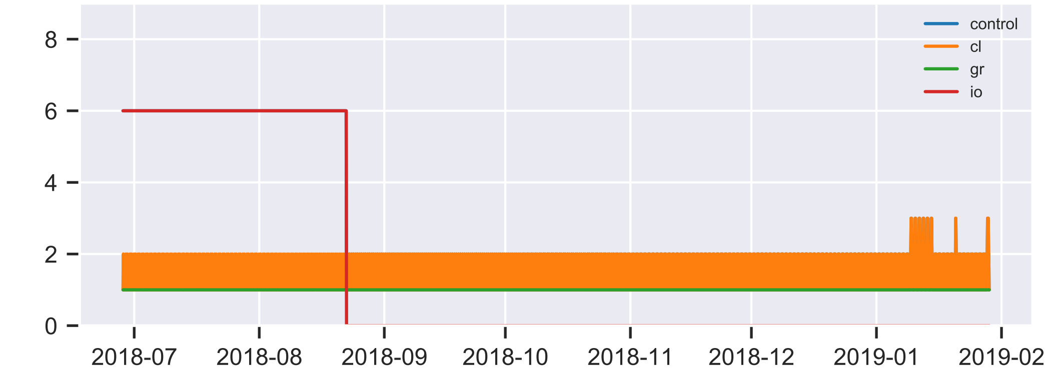


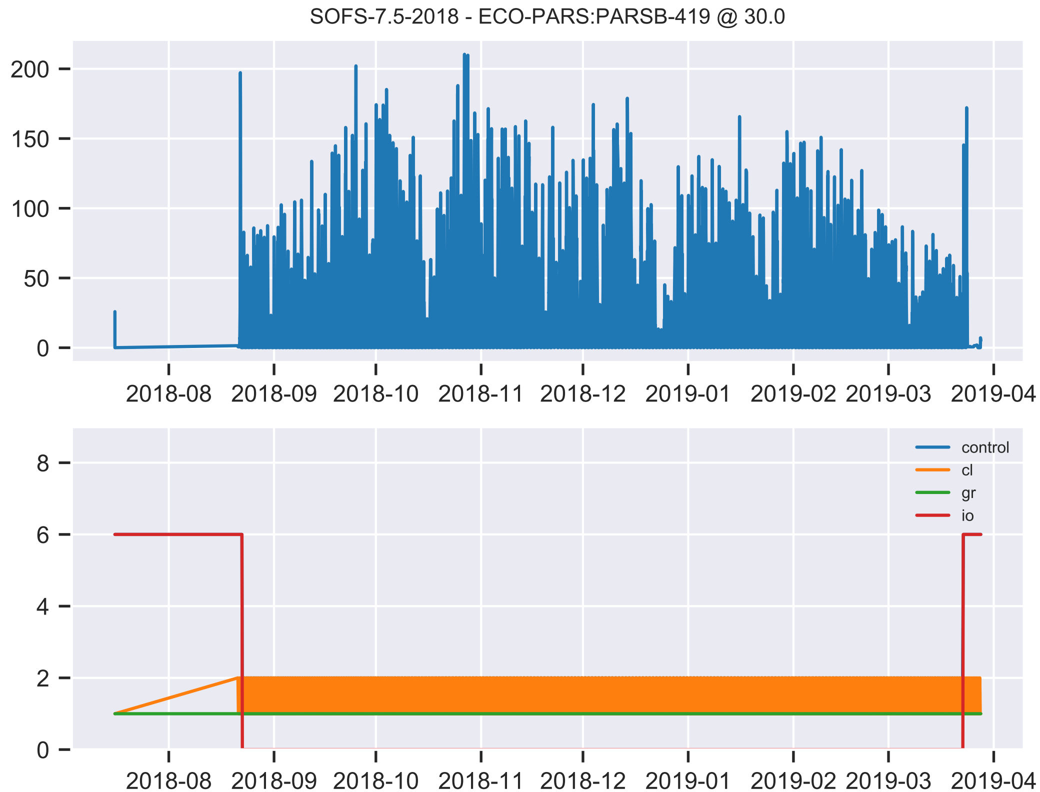
SOFS-5-2015 - MDS-MKVL:201319 @ 40.0
1500
1000
500
0
2015-03-22
2015-04-01
2015-04-08
2015-04-15
2015-04-22
2015-05-01
2015-05-08
2015-05-15
8
6
4
2
0
control
cl
gr
io


SOFS-6-2017 - LI-190SA:Q47470 @ -1.8
1000
500
0
−500
8
6
4
2
0
2017-03
2017-04
2017-05
2017-06
2017-07
2017-08
2017-09
2017-10
2017-11
2017-12
control
cl
gr
io

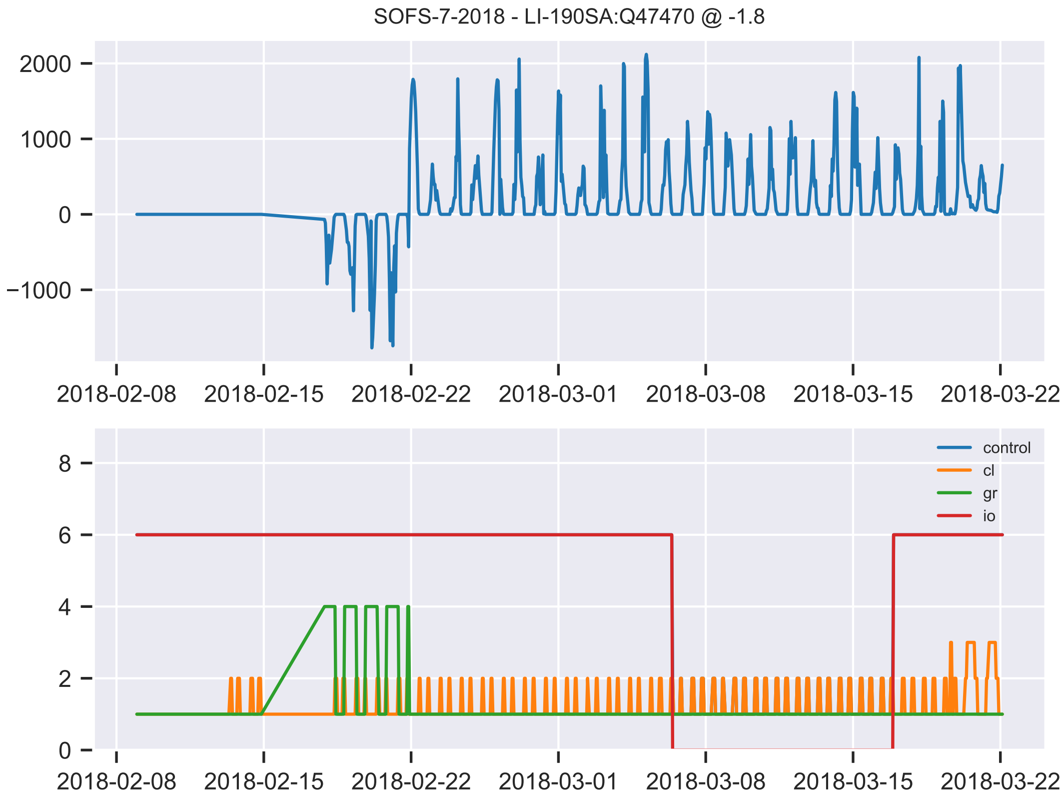
SOFS-7.5-2018 - LI-190SA:Q47470 @ -2.0







SOFS-7.5-2018 - ECO-PARS:PARSB-419 @ 30.0
200
150
100
50
0
2018-08
2018-09
2018-10
2018-11
2018-12
2019-01
2019-02
2019-03
2019-04
8
6
4
2
0
control
cl
gr
io



SOFS-7-2018 - LI-190SA:Q47470 @ -1.8
2000
1000
0
−1000
2018-02-08
2018-02-15
2018-02-22
2018-03-01
2018-03-08
2018-03-15
2018-03-22
8
6
4
2
0
control
cl
gr
io

9 Accessing the Data

Data are provided on-line from the Australian Ocean Data Network in CF compliant netcdf format files, with one file per deployment. We recommend using all data with flags of 1 or 2.

The URL for data access is:

https://portal.aodn.org.au/

Data file structure

```
variables:
	double TIME(TIME) ;
		TIME:long_name = "time" ;
		TIME:units = "days since 1950-01-01 00:00:00 UTC" ;
		TIME:calendar = "gregorian" ;
		TIME:axis = "T" ;
		TIME:standard_name = "time" ;
		TIME:valid_max = 90000. ;
		TIME:valid_min = 0. ;
	double NOMINAL_DEPTH ;
		NOMINAL_DEPTH:axis = "Z" ;
		NOMINAL_DEPTH:long_name = "nominal depth" ;
		NOMINAL_DEPTH:positive = "down" ;
		NOMINAL_DEPTH:reference_datum = "sea surface" ;
		NOMINAL_DEPTH:standard_name = "depth" ;
		NOMINAL_DEPTH:units = "m" ;
		NOMINAL_DEPTH:valid_max = 12000. ;
		NOMINAL_DEPTH:valid_min = -5. ;
	double LATITUDE ;
		LATITUDE:axis = "Y" ;
		LATITUDE:long_name = "latitude" ;
		LATITUDE:reference_datum = "WGS84 geographic coordinate system" ;
		LATITUDE:standard_name = "latitude" ;
		LATITUDE:units = "degrees_north" ;
		LATITUDE:valid_max = 90. ;
		LATITUDE:valid_min = -90. ;
	double LONGITUDE ;
		LONGITUDE:axis = "X" ;
		LONGITUDE:long_name = "longitude" ;
		LONGITUDE:reference_datum = "WGS84 geographic coordinate system" ;
		LONGITUDE:standard_name = "longitude" ;
		LONGITUDE:units = "degrees_east" ;
		LONGITUDE:valid_max = 180. ;
		LONGITUDE:valid_min = -180. ;
	float PAR_COUNT(TIME) ;
		PAR_COUNT:sensor_SeaVoX_L22_code = "SDN:L22::TOOL0676" ;
		PAR_COUNT:comment_attached_instrument = "Wet-LABS ; PARS-419" ;
		PAR_COUNT:calibration_PAR_Im = 1.3589 ;
		PAR_COUNT:calibration_PAR_digital_A1 = 2923. ;
		PAR_COUNT:calibration_PAR_digital_A0 = 4266. ;
		PAR_COUNT:calibration_PAR_date = "9/5/2014" ;
		PAR_COUNT:calibration_PAR_facility = "Satlantic" ;
		PAR_COUNT:calibration_PAR_SN = "PARSB-419" ;
	float PAR(TIME) ;
		PAR:_FillValue = NaNf ;
		PAR:sensor_SeaVoX_L22_code = "SDN:L22::TOOL0676" ;
		PAR:comment_attached_instrument = "Wet-LABS ; PARS-419" ;
		PAR:calibration_PAR_Im = 1.3589 ;
		PAR:calibration_PAR_digital_A1 = 2923. ;
		PAR:calibration_PAR_digital_A0 = 4266. ;
		PAR:calibration_PAR_date = "9/5/2014" ;
		PAR:calibration_PAR_facility = "Satlantic" ;
		PAR:calibration_PAR_SN = "PARSB-419" ;
		PAR:standard_name = "downwelling_photosynthetic_photon_flux_in_sea_water" ;
		PAR:long_name = "downwelling_photosynthetic_photon_flux_in_sea_water" ;
		PAR:units = "umol/m2/s" ;
		PAR:comment_sensor_type = "cosine sensor, with integrated anti-fouling Bio-wiper" ;
		PAR:ancillary_variables = "Final Io
					  Gr Cl" ;
	byte Final(TIME) ;
		Final:_FillValue = 99b ;
		Final:long_name = "quality_code for downwelling_photosynthetic_photon_flux_in_sea_water" ;
	float ALT(TIME) ;
		ALT:_FillValue = NaNf ;
		ALT:units = "degree" ;
		ALT:long_name = "sun_altitude" ;
		ALT:coordinates = "TIME LATITUDE LONGITUDE NOMINAL_DEPTH" ;
		ALT:comment = "using http://docs.pysolar.org/en/latest/ v0.8 get_altitude" ;
	float SOLAR(TIME) ;
		SOLAR:_FillValue = NaNf ;
		SOLAR:units = "W/m2" ;
		SOLAR:long_name = "incoming_solar_radiation" ;
```

```
		SOLAR:coordinates = "TIME LATITUDE LONGITUDE NOMINAL_DEPTH" ;
		SOLAR:comment = "using http://docs.pysolar.org/en/latest/ v0.8 extraterrestrial_irrad()
					with incoming = 1361 W/m^2" ;
	float ePAR(TIME) ;
		ePAR:_FillValue = NaNf ;
		ePAR:units = "umol/m^2/s" ;
		ePAR:long_name = "incoming_solar_radiation converted to PAR (x2.114) attenuated by depth" ;
		ePAR:coordinates = "TIME LATITUDE LONGITUDE NOMINAL_DEPTH" ;
		ePAR:comment = "using http://docs.pysolar.org/en/latest/ v0.8 extraterrestrial_irrad()
					with incoming = 1361 W/m^2, x 2.114, kd = 0.04" ;
	byte Io(TIME) ;
		Io:_FillValue = 99b ;
		Io:long_name = "quality flag for downwelling_photosynthetic_photon_flux_in_sea_water" ;
		Io:standard_name = "downwelling_photosynthetic_photon_flux_in_sea_water status_flag" ;
		Io:quality_control_conventions = "IMOS standard flags" ;
		Io:flag_values = 0b, 1b, 2b, 3b, 4b, 6b, 7b, 9b ;
		Io:flag_meanings = "unknown good_data probably_good_data probably_bad_data
					bad_data not_deployed interpolated missing_value" ;
		Io:comment = "data flagged not deployed (6) when out of water" ;
	byte Gr(TIME) ;
		Gr:_FillValue = 99b ;
		Gr:long_name = "quality flag for downwelling_photosynthetic_photon_flux_in_sea_water" ;
		Gr:standard_name = "downwelling_photosynthetic_photon_flux_in_sea_water status_flag" ;
		Gr:flag_values = 0b, 1b, 2b, 3b, 4b, 6b, 7b, 9b ;
		Gr:quality_control_conventions = "IMOS standard flags" ;
		Gr:flag_meanings = "unknown good_data probably_good_data probably_bad_data
					bad_data not_deployed interpolated missing_value" ;
		Gr:comment = "Test 4. gross range test" ;
	byte Cl(TIME) ;
		Cl:_FillValue = 99b ;
		Cl:long_name = "quality flag for downwelling_photosynthetic_photon_flux_in_sea_water" ;
		Cl:standard_name = "downwelling_photosynthetic_photon_flux_in_sea_water status_flag" ;
		Cl:quality_control_conventions = "IMOS standard flags" ;
		Cl:flag_values = 0b, 1b, 2b, 3b, 4b, 6b, 7b, 9b ;
		Cl:flag_meanings = "unknown good_data probably_good_data probably_bad_data
				bad_data not_deployed interpolated missing_value" ;
		Cl:comment = "Test 7. climatology test" ;
		Cl:comment_note = "cosine sensor, par < (2 * SOLAR) + 15" ;
	float SWR(TIME) ;
		SWR:_FillValue = NaNf ;

// global attributes:
		:abstract = "Oceanographic and meteorological data from the Southern Ocean Time Series observatory in
					the Southern Ocean southwest of Tasmania" ;
		:acknowledgement = "Any users of IMOS data are required to clearly acknowledge the source of the material
					derived from IMOS in the format: \"Data was sourced from the Integrated Marine
					Observing System (IMOS) - IMOS is a national collaborative research infrastructure,
					supported by the Australian Government.\" If relevant, also credit other organisations
					involved in collection of this particular datastream (as listed in \'credit\' in the
					metadata record)." ;
		:author = "Jansen, Peter" ;
		:author_email = "peter.jansen@csiro.au" ;
		:citation = "The citation in a list of references is: \'IMOS [year-of-data-download], [Title],
				[data-access-URL], accessed [date-of-access]\'." ;
		:comment = "Geospatial vertical min/max information has been filled using the NOMINAL_DEPTH." ;
		:Conventions = "CF-1.6,IMOS-1.4" ;
		:data_centre = "Australian Ocean Data Network (AODN)" ;
		:data_centre_email = "info@aodn.org.au" ;
		:deployment_code = "SOFS-7.5-2018" ;
		:disclaimer = "Data, products and services from IMOS are provided \"as is\" without any warranty as
					to fitness for a particular purpose." ;
		:featureType = "timeSeries" ;
		:file_version_quality_control = "Raw data is defined as unprocessed data and data products that have
				not undergone quality control. The data may be in engineering physical units, time and
				location details can be in relative units and values can be pre-calibration measurements." ;
		:geospatial_lat_max = -47.02274 ;
		:geospatial_lat_min = -47.02274 ;
		:geospatial_lat_units = "degrees_north" ;
		:geospatial_lon_max = 142.23341 ;
		:geospatial_lon_min = 142.23341 ;
		:geospatial_lon_units = "degrees_east" ;
		:geospatial_vertical_max = 30. ;
		:geospatial_vertical_min = 30. ;
		:geospatial_vertical_positive = "down" ;
		:institution = "DWM-SOTS" ;
		:institution_references = "http://www.imos.org.au/aodn.html" ;
		:instrument = "Wet-LABS ; ECO-PARS" ;
		:instrument_model = "ECO-PARS" ;
		:instrument_nominal_depth = 30. ;
		:instrument_serial_number = "PARSB-419" ;
		:keywords_vocabulary = "IMOS parameter names.
						See https://github.com/aodn/imos-toolbox/blob/master/IMOS/imosParameters.txt" ;
		:license = "http://creativecommons.org/licenses/by/4.0/" ;
		:naming_authority = "IMOS" ;
		:platform_code = "SOFS" ;
		:principal_investigator = "Trull, Tom" ;
		:principal_investigator_email = "tom.trull@csiro.au" ;
		:project = "Integrated Marine Observing System (IMOS)" ;
		:references = "http://www.imos.org.au" ;
		:site_code = "SOTS" ;
		:site_nominal_depth = 4624. ;
		:standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention Standard Name Table 67" ;
		:time_coverage_end = "2019-03-28T04:27:42Z" ;
		:time_coverage_start = "2018-07-16T03:05:34Z" ;
		:time_deployment_end = "2019-03-22T21:40:39Z" ;
		:time_deployment_start = "2018-08-22T13:17:54Z" ;
```

```
:title = "Oceanographic mooring data deployment of SOFS at latitude -47.0 longitude 142.2 depth
       30 (m) instrument WetLABs ; ECO-PARS serial PARSB-419" ;
:voyage_deployment = "http://www.cmar.csiro.au/data/trawler/survey_details.cfm?survey=IN2018_V07" ;
:voyage_recovery = "http://www.cmar.csiro.au/data/trawler/survey_details.cfm?survey=IN2019_V02" ;
:date_created = "2020-06-17T04:51:10Z" ;
:file_version = "Level 1 - Quality Controlled Data" ;
:history = "2020-05-13 created from file data/PAR/raw_files/SOFS-7.5-2018/PARSB-419.raw
            2020-05-13 : attributes added from file(s) [metadata/sofs-7.5.metadata.csv,
                            metadata/imos.metadata.csv, metadata/sots.metadata.csv,
                            metadata/sofs.metadata.csv, metadata/variable.metadata.csv]
       2020-05-13 : extracted from
         IMOS_DWM-SOTS_R_20180716_SOFS_FV00_SOFS-7.5-2018-ECO-PARS-PARSB-419-30m_END-20190328_C-20200513.nc
       2020-05-13 : added incoming radiation
       2020-06-17 : quality_control variables added.
       2020-06-17 : in-out water  marked 795
       2020-06-17 PAR global range min = -1.7 max = 10000 marked 0
       2020-06-17 PAR global range min = -1.7 max = 4500 marked 0
       2020-06-17 PAR climate range, marked 0"
```

Variables in netCDF file,

PAR downwelling_photosynthetic_photon_flux_in_sea_water

ALT sun_altitude
At location

SOLAR incoming_solar_radiation
At location

ePAR incoming_solar_radiation converted to PAR (x2.114) attenuated by depth

SWR Short Wave radiation from nearest sensor

10 References

Biggs, William W., Principles of Radiation Measurement, LiCor, https://www.licor.com/env/applications/photosynthetically.html

Britton, C.M., Dodd, J.D. (1976), Relationships of photosynthetically active radiation and shortwave irradiance. Agricultural Meteorology 17: 1-7.

Eriksen, R., T. W. Trull, D. Davies, P. Jansen, A. T. Davidson, K. Westwood, and R. van den Enden (2018), Seasonal succession of phytoplankton community structure from autonomous sampling at the Australian Southern Ocean Time Series (SOTS) observatory, Marine Ecology Progress Series, 589, 13-31, doi:10.3354/meps12420.

Herraiz-Borreguero, L., Rintoul, S.R. (2011), Regional circulation and its impact on upper ocean variability south of Tasmania (Australia). Deep-Sea Research II 58: 2071-2081.

Kirk, J.T.O. (1994), Light and Photosynthesis in Aquatic Ecosystems. Cambridge University Press, Cambridge.

McCree, J. K. (1972), Test of current definitions of photosynthetically active radiation against leaf photosynthesis data *Agricultural Meteorology*, *10*, 443-453.

Morel, A., Y. Huot, B. Gentili, P. J. Werdell, S. B. Hooker, and B. A. Franz (2007), Examining the consistency of products derived from various ocean color sensors in open ocean (Case 1) waters in the perspective of a multi-sensor approach, *Remote Sensing of Environment*, *111*(1), 69-88.

Schallenberg C., Harley J.W., Jansen P., Davies D.M. and Trull T.W. (2019) Multi-Year Observations of Fluorescence and Backscatter at the Southern Ocean Time Series (SOTS) Shed Light on Two Distinct Seasonal Bio-Optical Regimes. Front. Mar. Sci. 6:595.doi: 10.3389/fmars.2019.00595

Trull, T.W., Bray, S.G., Manganini, S.J., Honjo, S., François, R. (2001), Moored sediment trap measurements of carbon export in the Subantarctic and Polar Frontal Zones of the Southern Ocean, south of Australia. Journal of Geophysical Research 106: 31489-31510.

Appendix A Python code used for processing

Please refer to the following link for access to the R and Matlab files involved in performing the QC tests described in this report:

https://github.com/petejan/sots

https://github.com/petejan/imos-tools

Appendix B Sensor Calibration Sheets

Attached below are the calibration sheets for all PAR sensors deployed at the SOTS site.

Light Intensity Calibration Certificate

Model	:	DEFI-L
Serial No.	:	082V022
Date	:	February 06, 2013
Location	:	Kobe Production Section
Method	:	Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μmol/(m^2·s).

1. Equation

Instrument light quantum[μmol/(m^2·s)] = A+B × N   N: A/D value

2. Coefficients

A = +1.261990e+04   B = −1.945354e−01

Immersion effect: 1.42

3. Calibration results

Acceptance: ±4% of full scale

Reference light quantum [μmol/(m^2·s)]	A/D value	Instrument light quantum [μmol/(m^2·s)]	Residual error [μmol/(m^2·s)]	Acceptance [μmol/(m^2·s)]	OK/NG
0	64872	0.0	0.0	±200.0	OK
534	62162	527.2	−6.8	±200.0	OK
1017	59680	1010.0	−7.0	±200.0	OK
1530	57010	1529.4	−0.6	±200.0	OK
2013	54495	2018.7	5.7	±200.0	OK

4. Verification

Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

Acceptance: ±4% of full scale

Reference light quantum [μmol/(m^2·s)]	Instrument light quantum [μmol/(m^2·s)]	Residual error [μmol/(m^2·s)]	Acceptance [μmol/(m^2·s)]	Judgement
1060	1085.4	25.4	±200.0	Passed

Examined H. Yamane

Approved T. Nishimura

JFE Advantech Co., Ltd.

Light Intensity Calibration Certificate

Model	:	DEFI-L
Serial No.	:	082V025
Date	:	February 08, 2013
Location	:	Kobe Production Section
Method	:	Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μmol/(m^2·s).

1. Equation

Instrument light quantum[μmol/(m^2·s)] = A+B × N   N: A/D value

2. Coefficients

A = +1.276023e+04   B = −1.966834e−01

Immersion effect: 1.43

3. Calibration results

Acceptance: ±4% of full scale

Reference light quantum [μmol/(m^2·s)]	A/D value	Instrument light quantum [μmol/(m^2·s)]	Residual error [μmol/(m^2·s)]	Acceptance [μmol/(m^2·s)]	OK/NG
0	64877	0.0	0.0	±200.0	OK
558	62081	549.9	−8.1	±200.0	OK
1042	59604	1037.1	−4.9	±200.0	OK
1504	57240	1502.1	−1.9	±200.0	OK
2028	54535	2034.1	6.1	±200.0	OK

4. Verification

Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

Acceptance: ±4% of full scale

Reference light quantum [μmol/(m^2·s)]	Instrument light quantum [μmol/(m^2·s)]	Residual error [μmol/(m^2·s)]	Acceptance [μmol/(m^2·s)]	Judgement
1008	985.5	−22.5	±200.0	Passed

Examined H. Yamane

Approved T. Nishimura

JFE Advantech Co., Ltd.

Light Intensity Calibration Certificate

Model	:	DEFI-L
Serial No.	:	082V024
Date	:	February 08, 2013
Location	:	Kobe Production Section
Method	:	Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μ mol/(m^2·s).

1. Equation

Instrument light quantum[μ mol/(m^2·s)] = A+B × N   N: A/D value

2. Coefficients

A = +1.233661e+04   B = −1.901802e−01

Immersion effect: 1.38

3. Calibration results

Acceptance: ±4% of full scale

Reference light quantum [μ mol/(m^2·s)]	A/D value	Instrument light quantum [μ mol/(m^2·s)]	Residual error [μ mol/(m^2·s)]	Acceptance [μ mol/(m^2·s)]	OK/NG
0	64868	0.0	0.0	±200.0	OK
541	62061	533.8	−7.2	±200.0	OK
1020	59539	1013.5	−6.5	±200.0	OK
1540	56769	1540.3	0.3	±200.0	OK
2030	54168	2034.9	4.9	±200.0	OK

4. Verification

Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

Acceptance: ±4% of full scale

Reference light quantum [μ mol/(m^2·s)]	Instrument light quantum [μ mol/(m^2·s)]	Residual error [μ mol/(m^2·s)]	Acceptance [μ mol/(m^2·s)]	Judgement
1026	999.6	−26.4	±200.0	Passed

Examined H. Yamane

Approved T. Nishimura

JFE Advantech Co., Ltd.

Light Intensity Calibration Certificate

Model : DEFI-L
Serial No. : 082V023
Date : February 06, 2013
Location : Kobe Production Section
Method : Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μ mol/(m²·s).

1. Equation

Instrument light quantum[μ mol/(m²·s)] = A+B × N   N: A/D value

2. Coefficients

A = +1.191277e+04   B = −1.836407e−01

Immersion effect: 1.39

3. Calibration results

Acceptance: ±4% of full scale

Reference light quantum [μ mol/(m²·s)]	A/D value	Instrument light quantum [μ mol/(m²·s)]	Residual error [μ mol/(m²·s)]	Acceptance [μ mol/(m²·s)]	OK/NG
0	64870	0.0	0.0	±200.0	OK
518	62085	511.4	−6.6	±200.0	OK
1021	59345	1014.6	−6.4	±200.0	OK
1511	56655	1508.6	−2.4	±200.0	OK
2025	53807	2031.6	6.6	±200.0	OK

4. Verification

Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

Acceptance: ±4% of full scale

Reference light quantum [μ mol/(m²·s)]	Instrument light quantum [μ mol/(m²·s)]	Residual error [μ mol/(m²·s)]	Acceptance [μ mol/(m²·s)]	Judgement
1036	1001.2	−34.8	±200.0	Passed

Examined H. Yamane

Approved T. Nishimura

JFE Advantech Co., Ltd.

Light Intensity Calibration Certificate

Model	:	DEFI2-L
Serial No.	:	0AA0010
Date	:	December 16, 2015
Location	:	Production Section
Method	:	Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μmol/(m²·s).

1. Equation

   Instrument light quantum[μmol/(m²·s)] = A+B×N N: A/D value

2. Coefficients

   A = +9.755507e+03 B = −1.503739e−01

   Immersion effect: 1.40

3. Calibration results

   Acceptance: ±0.9% of full scale

Reference light quantum [μmol/(m²·s)]	A/D value	Instrument light quantum [μmol/(m²·s)]	Residual error [μmol/(m²·s)]	Acceptance [μmol/(m²·s)]	OK/NG
0	64875	0.0	0.0	±45.0	OK
513	61465	512.8	-0.2	±45.0	OK
1012	58174	1007.7	-4.3	±45.0	OK
1515	54787	1517.0	2.0	±45.0	OK
2009	51510	2009.7	0.7	±45.0	OK

4. Verification

   Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

   Acceptance: ±3.5% of full scale

Reference light quantum [μmol/(m²·s)]	Instrument light quantum [μmol/(m²·s)]	Residual error [μmol/(m²·s)]	Acceptance [μmol/(m²·s)]	Judgement
1913	1915.3	2.3	±175.0	Passed

Examined R. Shimozato

Approved A. Fukuoka

JFE Advantech Co., Ltd.

Light Intensity Calibration Certificate

Model : DEFI2-L
Serial No. : 0AA0011
Date : December 16, 2015
Location : Production Section
Method : Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μmol/(m²·s).

1. Equation

Instrument light quantum[μmol/(m²·s)] = A+B × N N: A/D value

2. Coefficients

A = +9.428665e+03 B = −1.453336e−01
Immersion effect: 1.39

3. Calibration results

Acceptance: ±0.9% of full scale

Reference light quantum [μmol/(m²·s)]	A/D value	Instrument light quantum [μmol/(m²·s)]	Residual error [μmol/(m²·s)]	Acceptance [μmol/(m²·s)]	OK/NG
0	64876	0.0	0.0	±45.0	OK
513	61313	517.8	4.8	±45.0	OK
1014	57937	1008.5	−5.5	±45.0	OK
1513	54489	1509.6	−3.4	±45.0	OK
2013	50997	2017.1	4.1	±45.0	OK

4. Verification

Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

Acceptance: ±3.5% of full scale

Reference light quantum [μmol/(m²·s)]	Instrument light quantum [μmol/(m²·s)]	Residual error [μmol/(m²·s)]	Acceptance [μmol/(m²·s)]	Judgement
1908	1885.0	−23.0	±175.0	Passed

Examined R. Shimozato

Approved A. Fukuoka

JFE Advantech Co., Ltd.

Light Intensity Calibration Certificate

Model : DEFI2-L
Serial No. : 0AQH011
Date : August 02, 2017
Location : Production Section
Method : Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μmol/(m^2·s).

1. Equation

Instrument light quantum[μmol/(m^2·s)] = A+B × N N: A/D value

2. Coefficients

A = +9.617790e+03 B = −1.482488e−01

Immersion effect: 1.43

3. Calibration results

Acceptance: ±0.9% of full scale

Reference light quantum [μmol/(m^2·s)]	A/D value	Instrument light quantum [μmol/(m^2·s)]	Residual error [μmol/(m^2·s)]	Acceptance [μmol/(m^2·s)]	OK/NG
0	64876	0.0	0.0	±45.0	OK
546	61184	547.3	1.3	±45.0	OK
1004	58073	1008.5	4.5	±45.0	OK
1486	54828	1489.6	3.6	±45.0	OK
2121	50603	2116.0	−5.0	±45.0	OK

4. Verification

Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

Acceptance: ±3.5% of full scale

Reference light quantum [μmol/(m^2·s)]	Instrument light quantum [μmol/(m^2·s)]	Residual error [μmol/(m^2·s)]	Acceptance [μmol/(m^2·s)]	Judgement
2132	2104.0	−28.0	±175.0	Passed

Examined M. Kano

Approved A. Fukuoka

JFE Advantech Co., Ltd.

Light Intensity Calibration Certificate

Model : DEFI2-L
Serial No. : 0AQH012
Date : August 09, 2017
Location : Production Section
Method : Calibration equation is determined from linear regression of samples of the reference light quantum against A/D values. Samples are taken at approximately 0, 500, 1000, 1500, and 2000 μ mol/(m^2·s).

1. Equation

Instrument light quantum[μ mol/(m^2·s)] = A+B × N   N: A/D value

2. Coefficients

A = +9.933032e+03   B = −1.530985e−01

Immersion effect: 1.42

3. Calibration results

Acceptance: ±0.9% of full scale

Reference light quantum [μ mol/(m^2·s)]	A/D value	Instrument light quantum [μ mol/(m^2·s)]	Residual error [μ mol/(m^2·s)]	Acceptance [μ mol/(m^2·s)]	OK/NG
0	64880	0.0	0.0	±45.0	OK
528	61363	538.4	10.4	±45.0	OK
989	58400	992.1	3.1	±45.0	OK
1464	55294	1467.6	3.6	±45.0	OK
2089	51279	2082.3	−6.7	±45.0	OK

4. Verification

Criteria of judgement : Residual error of the instrument light quantum at arbitrary point is within the acceptance value.

Acceptance: ±3.5% of full scale

Reference light quantum [μ mol/(m^2·s)]	Instrument light quantum [μ mol/(m^2·s)]	Residual error [μ mol/(m^2·s)]	Acceptance [μ mol/(m^2·s)]	Judgement
2060	1945.0	−115.0	±175.0	Passed

Examined M. Kano

Approved A. Fukuoka

JFE Advantech Co., Ltd.

CERTIFICATE OF CALIBRATION

Model Number: **LI-190SA QUANTUM SENSOR**

Serial Number: Q40966

Calibration Constant: 6.26

Units: microamps per 1000 µmol s-1 m-2

Calibration Multiplier: -159.74

Units: µmol s-1 m-2 per microamp

Please consult the instruction manual for further information on the calibration constant and calibration multiplier. Recalibration is recommended every two years.

Date of Calibration: May 21, 2009

By: Cameron Deschane

LI-COR® Biosciences

4421 Superior Street ● P.O. Box 4425 ● Lincoln, Nebraska 68504 USA
Phone: 402-467-3576 ● FAX: 402-467-2819
Toll-free 1-800-447-3576 (U.S. & Canada)
E-mail: envsales@licor.com
www.licor.com

CERTIFICATE of CALIBRATION
for LI-COR SENSOR

Quantum Sensor
Model Number: LI-190

Serial Number: **Q47470**

Calibration Date: **March 02, 2012**
Manufacture Date: **March 01, 2012**

Calibration Constant:

Output: **8.19** microamps per 1000 μmol s^{-1} m^{-2}

For use with LI-COR handheld meters:

Multiplier: **-122.04** μmol s^{-1} m^{-2} per microamp

For use with LI-COR 2290 (604 ohm) Millivolt Adapter:

Multiplier: **-202.05** μmol s^{-1} m^{-2} per millivolt

If this is an SL sensor:

Multiplier: **-200.0** μmol s^{-1} m^{-2} per millivolt

IMPORTANT: Read the appropriate instruction manual (http://www.licor.com/TSM) before using this sensor.
IMPORTANT: It is recommended that sensors be recalibrated every two years.

Calibration Technician: ____________

Calibration standard used: Working standard lamp 797H.
Calibration traceable to the National Institute of Standards and Technologies (NIST) through NIST-calibration lamp number F-226.
(NBS Test No. 534/237689-86)

LI-COR Biosciences

LI-COR Biosciences • Environmental • 4421 Superior Street • P.O Box 4425 • Lincoln, NE 68504 USA
Phone: (1) 402-467-3576 • Fax: 402-467-2819 • Toll-free: 800-447-3576 (USA & Canada)
envsales@licor.com • envsupport@licor.com • www.licor.com
Manual: http://www.licor.com/TSM

Light Intensity

MODEL : MDS MKV/L

SERIAL No : 200341

DATE : 21-May-2010

Loaction : Calibration office of manfacture department at Kobe

Method : Light sensor is calibrated by 4 levels of light intensity ranging from 0 to 3000 μmol/m2s with each level difference about 1000 μmol/m2s. The outputs are computed by a linear regression agaiinst their correspondi reference readings from a standard light quantum meter.

Referece device : Light quantum meter ("LI-COR" Model: LI-189)

Formula : Light quantum (μ mol/m^2s) = A + B × N

A = -1.05326E+00

B = 1.05326E+00

Immersion effect 0.00

Reference (μ mol/m^2s)	Output N	Calculated (μ mol/m^2s)	Error (μ mol/m^2s)
0.0	1	0.0	0.0
503.0	462	485.6	-17.4
1036.0	962	1012.2	-23.8
2045.0	1934	2036.0	-9.0
3060.0	2922	3076.6	16.6

Criteria for acceptability : 1. The errors in above form must be within ±4% FS
2. After writing the calibration coefficients into instrument, one point check at any level of light must agree with the accuracy declared by the instrument.

Reference (μ mol/m^2s)	Output (μ mol/m^2s)	Error (μ mol/m^2s)
1440	1426	-14

Judgement : **Good**

Calibration group,

Manufacture department at Kobe

JFE Advantech Co., LTD

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Light Intensity

MODEL : MDS MKV/L

SERIAL No : 200665

DATE : 21-May-2010

Loaction : Calibration office of manfacture department at Kobe

Method : Light sensor is calibrated by 4 levels of light intensity ranging from 0 to 3000 μmol/m2s with each level difference about 1000 μmol/m2s.
The outputs are computed by a linear regression againist their correspondi
reference readings from a standard light quantum meter.

Referece device : Light quantum meter ("LI-COR" Model: LI-189)

Formula : Light quantum (μ mol/m^2s) $= A + B \times N$

A = -1.13690E+00

B = 1.13690E+00

Immersion effect 0.00

Reference (μ mol/m^2s)	Output N	Calculated (μ mol/m^2s)	Error (μ mol/m^2s)
0.0	1	0.0	0.0
500.0	429	486.6	−13.4
1090.0	940	1067.5	−22.5
2033.0	1782	2024.8	−8.2
3100.0	2741	3115.1	15.1

Criteria for acceptability : 1. The errors in above form must be within ±4% FS
2. After writing the calibration coefficients into instrument, one point check at any level of light must agree with the accuracy declared by the instrument.

Reference (μ mol/m^2s)	Output (μ mol/m^2s)	Error (μ mol/m^2s)
1262	1251	-11

Judgement : **Good**

Calibration group,
Manufacture department at Kobe
JFE Advantech Co., LTD

Light Intensity

MODEL : MDS MKV/L

SERIAL No : 200664

DATE : 21-May-2010

Loaction : Calibration office of manfacture department at Kobe

Method : Light sensor is calibrated by 4 levels of light intensity ranging from 0 to 3000 μmol/m2s with each level difference about 1000 μmol/m2s. The outputs are computed by a linear regression againist their correspondir reference readings from a standard light quantum meter.

Referece device : Light quantum meter ("LI-COR" Model: LI-189)

Formula : Light quantum (μ mol/m^2s) $= A + B \times N$

A = -8.17469E-01

B = 8.17469E-01

Immersion effect 0.00

Reference (μ mol/m^2s)	Output N	Calculated (μ mol/m^2s)	Error (μ mol/m^2s)
0.0	1	0.0	0.0
500.0	591	482.3	-17.7
1041.0	1261	1030.0	-11.0
2003.0	2445	1997.9	-5.1
3027.0	3716	3036.9	9.9

Criteria for acceptability : 1. The errors in above form must be within ±4% FS
2. After writing the calibration coefficients into instrument, one point check at any level of light must agree with the accuracy declared by the instrument.

Reference (μ mol/m^2s)	Output (μ mol/m^2s)	Error (μ mol/m^2s)
1626	1612	-14

Judgement : **Good**

Calibration group,

Manufacture department at Kobe

JFE Advantech Co., LTD

PO Box 518
620 Applegate St.
Philomath OR 97370

WET Labs

(541) 929-5650
Fax (541) 929-5277
http://www.wetlabs.com

PARs Calibration Sheet

Date: Mar. 27, 2009 Customer: SeaBird Elec.

S/N#: PARS-135

Calibration Coefficients

	Analog	Digital
Im	= 1.3589	= 1.3589
a_1	= 0.8946	= 2943.4639
a_0	= 1.3285	= 4374.0529

Equations: $y = \text{Im}*10^{\frac{x-a_o}{a_1}}$, if the sensor is immersed in water

$y = 1.0*10^{\frac{x-a_o}{a_1}}$, if the sensor is not immersed

where,
PAR is y, $[y]$ = μmol photons/m^2/s
Count is x, $[x]$ = counts

For users of SEASOFT, Sea-Bird Electronics' data processing software, calibration coefficients are converted in accordance with Sea-Bird Electronics application note No. 11 QSP-L. The corresponding coefficients for use in SEASOFT are:

multiplier = 1.0 (in air)
multiplier = 1.3589 (in water)
M = 0.8946
B = 1.3285
Calibration_const = $1.0*10^9$
offset = 0

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PO Box 518
620 Applegate St.
Philomath OR 97370

(541) 929-5650
Fax (541) 929-5277
http://www.wetlabs.com

PARs Calibration Sheet

Date: Mar. 27, 2009 Customer: SeaBird Elec.

S/N#: PARS-134

Calibration Coefficients

	Analog	Digital
Im	= 1.3589	= 1.3589
a_1	= 0.8902	= 2923.6435
a_0	= 1.3145	= 4260.0842

Equations: $y = \text{Im} * 10^{\frac{x-a_o}{a_1}}$, if the sensor is immersed in water

$y = 1.0 * 10^{\frac{x-a_o}{a_1}}$, if the sensor is not immersed

where,
PAR is ***y***, [***y***] = µmol photons/m^2/s
Count is ***x***, [***x***] = counts

For users of SEASOFT, Sea-Bird Electronics' data processing software, calibration coefficients are converted in accordance with Sea-Bird Electronics application note No. 11 QSP-L. The corresponding coefficients for use in SEASOFT are:

multiplier = 1.0 (in air)
multiplier = 1.3589 (in water)
M = 0.8902
B = 1.3145
Calibration_const = $1.0*10^9$
offset = 0

PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

PARs Calibration Sheet

Date: 9/5/2014

S/N: PARSB-419

PAR Scale Factor

PAR = $Im*10((x-a_0)/a_1)$, if the sensor is immersed in water

PAR = $1.0*10((x-a_0)/a_1)$, if the sensor is not immersed

Where,

PAR = μmol photons/m^2/s

x = counts

	Analog	Digital
Im	1.3589	1.3589
a_1	0.893	2923
a_0	1.309	4266

For users of SEASOFT, Sea-Bird Electronics' data processing software, calibration coefficients are converted in accordance with Sea-Bird Electronics application note No. 11 QSP-L. The corresponding coefficients for use in SEASOFT are:

multiplier	**1**	In Air
multiplier	**1.359**	In Water
M	**0.893**	
B	**1.309**	
Calibration_const	**1.0*10^9**	
offset	**0**	

PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
Fax (541) 929-5277
www.seabird.com

PAR Calibration Sheet

Date: 4/9/2020 S/N: PARSB-419

PAR Scale Factor

$$PAR = Im*10^{(x-a_0)/a_1}$$ if the sensor is immersed in water

$$PAR = 1.0*10^{(x-a_0)/a_1}$$ if the sensor is not immersed

Where,

PAR = µmol photons/m^2/s

x = counts

	Analog	Digital
Im	1.3589	1.3589
a_1	0.886	2902
a_0	1.364	4442

For users of SEASOFT, Sea-Bird Electronics' data processing software, calibration coefficients are converted in accordance with Sea-Bird Electronics application note No. 11 QSP-L. The corresponding coefficients for use in SEASOFT are:

multiplier	**1**	In Air
multiplier	**1.359**	In Water
M	**0.886**	
B	**1.364**	
Calibration_const	**1.0*10^9**	
offset	**0**	

Document Version Control and Change Register

Version	Date	Change Description	Revision Authors
1.0	13 June 2019	Original version	Harley et al.
2.0	18 Dec. 2020	Processed data through 2019 modified the Neighbour Test added comparison to FLNTUS chlorophyll added calculation of PAR Kd values	Peter Jansen and Tom Trull

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

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FOR FURTHER INFORMATION

Oceans and Atmosphere
Peter Jansen
t +61 3 6232 5094
e Peter.Jansen@csiro.au

Oceans and Atmosphere
Thomas Trull
t +61 3 6232 5069
e Tom.Trull@csiro.au