Oceans and Atmosphere

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



Photosynthetically Available Radiation Records

2009-2016

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Acknowledgments

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Executive summary

The Southern Ocean Time Series (SOTS) Observatory located at 140°E and 47°S provides high temporal resolution observations in sub-Antarctic waters. It is focused on the sub-Antarctic Zone because waters formed at the surface in this region slide under warmer subtropical and tropical waters, carrying CO2 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. The sub-Antarctic Zone and these processes are expected to change with global warming, but the potential impacts of these changes are not yet known.

This report details the quality control applied to the photosynthetically available radiation (PAR) data collected from the SOTS moorings between 2009 and 2016. The quality controlled datasets are publicly available via the IMOS Data Portal. This report should be consulted when using the data.

# Introduction

The Southern Ocean Time Series (SOTS) Observatory provides high temporal resolution observations in sub-Antarctic waters. Observations are broad and include measurements of physical, chemical and biogeochemical parameters from multiple deep-water moorings in the sub-Antarctic 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 and is one of the few comprehensive Southern Ocean sites globally. More information on the SOTS 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 CO2 emissions, and 75% of the additional heat that these emissions have trapped on Earth. The Southern Ocean Time Series site is focused on the sub-Antarctic Zone because waters formed at the surface in this region, the Sub-Antarctic Mode and Antarctic Intermediate waters, slide under warmer subtropical and tropical waters and carry this CO2 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 sub-Antarctic 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 140°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).

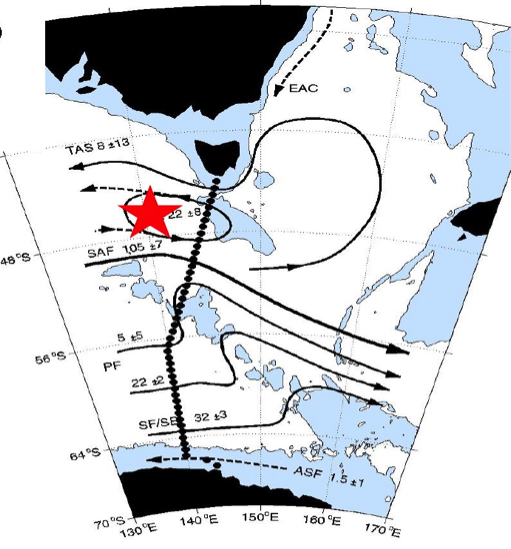


Figure 1 Location of the SOTS observatory; Figure adapted from Herraiz-Borreguero et al., 2011

# 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.

- 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 and turbidity. 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 radiometers, temperature and humidity sensors, precipitation gauges and sonic anemometers, and a pCO2 sensor provided by NOAA providing the measurements necessary for computing air-sea fluxes of CO2, heat, momentum and mass. Surface photosynthetically active radiation and surface UV are also measured to help assess light available for phytoplankton production. In the 2016-17 year, we combined the SOFS and Pulse capabilities into a single prototype mooring known as FluxPulse-1.

- 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.

- Surface data collected from the 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.

# Summary of Instruments

A total of ten different instruments for measuring PAR were deployed at SOTS between 2009 and 2015. 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 (also known as planar) sensors receive downwelling light through a flat surface and measure downwelling PAR as a vector quantity. These sensors tend to underestimate PAR as would be experienced by phytoplankton, as they are incapable of receiving upwelling light. However, they work well in measuring PAR out of the water or at the surface. These sensors also possess cosine correction, in the form of a material that diffuses light, reducing errors introduced by light hitting the sensor from lower incident angles. 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 whilst 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) |
| Licor | LI-190 | Q47470 | SOFS-4-2013 (Surface - in air)  SOFS-5-2015 (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) |

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) |

# 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 WET labs 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 5 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 in units of μmol m−2 s−1.

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

(equation 1.)

Where *Im* is an immersion correction, a0 is the reference PAR value at 0 counts and a1 accounts for the sensor’s sensitivity.

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

(equation 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.

# 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. Each test was applied to all data points, including those that had been flagged as fail or suspect in previous tests.

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

Table 4. Flags used in PAR quality control

|  |  |
| --- | --- |
| **Flag** | **Description** |
| Pass, Good data = 1 | Data have passed the highest level of quality control |
| Probably good = 2 | Data were unable to be evaluated by at least one test, but were not flagged as suspect or fail by any other tests |
| Suspect or of high interest = 3 | Data have failed one or more tests indicating suspicious values, however it is possible that sensor failure has not occurred |
| Fail = 4 | Data have failed one or more tests indicating instrument or mooring failure |
| Sensor active but not deployed = 5 | Data obtained when the sensor was out of water or not at the assigned depth |

## Applied tests

**Test 1. Timing/Gap Test:**

The timing/gap test checks that all measurements were made at the correct time intervals. No problems were found and therefore no flags were applied.

**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 0 or higher than 10,000 μmol m−2 s−1 were flagged as a fail (flag = 4). Any value above 4500 μmol m−2 s−1 was flagged as suspect (flag = 3).

**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 PAR at each depth were created from modelled incident solar irradiance at the surface, propagated to depth using the clear water value of the diffuse attenuation coefficient (Kd = 0.04). This is a conservative Kd value as seasonal variation is expected. Summer Kd values at the SOTS site have been measured at 0.1, 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. It factors in the absorbance of solar radiation due to the atmosphere.

Solar radiation values 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. All calculated solar radiation values were converted from short wave radiation in units of W m-2 to PAR in units of μmol m−2 s−1 using the *LakeMetabolizer* package for R, which uses a conversion coefficient of 2.114 (Britton and Dodd 1976).

Climatological PAR was calculated according to the following formula:

(equation 3.)

These PAR values represent the amount of light that would theoretically reach the sensors on a sunny, clear-sky day with completely clear water. Given that the water will never be completely clear, any measured values of PAR that fall above these estimated PAR values were flagged as a fail. Given that the surface estimates of PAR are likely to be closer to measured values, any PAR values found to be higher than estimated PAR at the surface were flagged as suspect.

This test becomes less useful during dawn and dusk as light conditions are not well represented by the solar radiation model and the test begins to flag a large number of values that may be of good quality. Therefore, all low PAR values were flagged as unevaluated given that this test cannot accurately be applied to them.

Any below surface data point showing a value higher than the modelled PAR value at that depth was assigned a flag of 4. Surface data points showing a value higher than the modelled PAR were assigned a flag of 3. All data points that were below a PAR value of 3 μmol m−2 s−1 were deemed unable to be evaluated by the test due to different light conditions at dusk and dawn and were assigned a flag value of 2.

**Test 9. Rate of Change Test:**

This test is applied to the night-time data from all sensors. The aim is to catch any sensors that exhibit sensor drift, which should be easily detectable using night values where no light is available. The night time PAR data was converted to nightly means with a corresponding standard deviation value calculated as the standard deviation of that point and the following six points, i.e. the nightly means for 7 days. Any sensor that varied between two nights by more than three standard deviations was flagged as a fail:

(equation 4.)

Any points returning TRUE for equation 4 were assigned a flag of 4. Any points that could not be evaluated due to not having enough subsequent points to calculate a standard deviation were assigned a flag value of 2.

**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. If a sensor returned 5 consecutive daytime measurements within a tolerance value of 0.1, the 5th value was flagged as a fail.

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:

(equation 5.)

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 given a more attenuated signal. The test thus consisted of comparing each sensor to those mounted below them on the mooring. If the daily mean readings from a sensor were observed to drop below multiple deeper sensors, the data were flagged as a failure. However, if readings from a sensor only fall below one other sensor, it becomes difficult to say which sensor is faulty, so in this scenario data from both sensors were listed as suspect.

Any sensor returning a daily mean PAR value that was lower than more than one deeper sensor was given a flag of 4. If a daily mean PAR value was lower than that from a single deeper sensor, then both data series were given a flag of 3 for that day. Any sensor that could not be compared to other sensors was considered unevaluated and assigned a flag value of 2.

## Flag statistics

Table 5. Flag counts from each deployment for each test

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| TEST | DEPLOYMENT | FLAG = 1 | FLAG = 2 | FLAG = 3 | FLAG = 4 |
| Gross Range | Pulse 6  Pulse 7  Pulse 8  Pulse 9  Pulse 10  Pulse 11  SOFS 1  SOFS 2  SOFS 3  SOFS 4  SOFS 5  **TOTAL** | 743081  945959  1265698  21650  707978  1034603  209320  240422  4097  309467  144103  **5626378** | N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  **N/A** | N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  **N/A** | 16  312  493  0  21  35  10501  20422  1  40910  13855  **86566** |
| Climatology | Pulse 6  Pulse 7  Pulse 8  Pulse 9  Pulse 10  Pulse 11  SOFS 1  SOFS 2  SOFS 3  SOFS 4  SOFS 5  **Totals** | 291596  389228  454422  11272  230513  467159  83665  126003  2058  123533  63251  **2242700** | 394817  520753  773130  10245  457415  566701  136069  133980  1880  224477  94110  **3313577** | 56683  36287  38619  0  20035  0  68  527  160  2348  594  **155321** | 1  3  20  133  36  778  19  334  0  19  3  **1346** |
| Rate of Change | Pulse 6  Pulse 7  Pulse 8  Pulse 9  Pulse 10  Pulse 11  SOFS 1  SOFS 2  SOFS 3  SOFS 4  SOFS 5  **Total** | 709452  913704  1234200  21085  679197  1014984  215506  251606  3954  330255  140397  **5514340** | 26445  25343  26231  565  25922  16606  4315  9238  144  20122  17561  **172492** | 7200  7224  5760  0  2880  3048  0  0  0  0  0  **26112** | N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  **N/A** |
| Flat Line | Pulse 6  Pulse 7  Pulse 8  Pulse 9  Pulse 10  Pulse 11  SOFS 1  SOFS 2  SOFS 3  SOFS 4  SOFS 5  **Totals** | 325454  416771  482044  11288  243089  466541  83247  125672  2152  122497  62910  **2341665** | 353375  470321  707574  10183  443274  558544  127924  129626  1898  220132  91820  **3114671** | N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  N/A  **N/A** | 64268  59179  76573  179  21636  9553  8650  5546  48  7748  3228  **256608** |
| Neighbour | Pulse 6  Pulse 7  Pulse 8  Pulse 9  Pulse 10  Pulse 11  SOFS 1  SOFS 2  SOFS 3  SOFS 4  SOFS 5  **Totals** | 642910  579869  1062635  21540  707999  890509  184879  208998  4070  350377  135369  **4789155** | 0  0  147  0  0  0  0  47  0  0  0  **194** | 43920  152608  201361  110  0  144129  11117  50967  28  0  22589  **626829** | 56267  213794  2048  0  0  0  23825  832  0  0  0  **296766** |
| Flag Totals | Pulse 6  Pulse 7  Pulse 8  Pulse 9  Pulse 10  Pulse 11  SOFS 1  SOFS 2  SOFS 3  SOFS 4  SOFS 5  **Totals** | 2677216  3215655  4468755  86760  2554236  3873473  776613  952651  16237  1236020  546004  **20403620** | 774637  1016417  1507082  20997  926611  1141851  268308  272891  3922  464731  203491  **6600938** | 153018  229760  280966  110  41432  147153  11244  51550  330  2575  23312  **941450** | 110614  269523  74152  383  17716  10713  42940  27128  1  48559  16983  **618712** |

## Discussion and recommendations

Recommended 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.

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.

An attempt was made to create a multivariate test that functioned in a similar way to the climatology test, using chlorophyll values to estimate Kd and therefore calculate expected PAR at different depths. However, there was not enough good quality chlorophyll data from the SOTS site to cover all the PAR measurements. It was thought that perhaps a fixed value of the highest chlorophyll concentration observed at the SOTS site could be used as a lower bound, below which PAR could not fall. However, this would only work on a clear day, as high chlorophyll in combination with clouds could push the PAR values below this bound. Ultimately it was decided that this test would not be useful to implement.

**How good are the data?**

The main obstacle to more thorough quality control of this dataset is the fact that it is difficult to distinguish sensor issues from the impact of cloudy days on PAR at the SOTS site. This QC effort could be significantly improved if this were addressed.

There are also many points that were flagged as suspect in the neighbour test due to a sensor at a shallower depth producing lower PAR values. While it is difficult for the test to show which of these sensors is at fault, it may be easier to determine visually by plotting the data from the sensors.

As mentioned in the introduction, it is possible that spherical sensors mounted above the sea surface may receive light reflected from the surface of the water. This is evident in the SOTS data, with surface spherical sensors producing PAR values much higher than those recorded by surface cosine sensors (Figure 2). The climatology test flags these points as suspect, because they are much higher than modelled PAR values estimated from solar radiation. The sensors are behaving correctly but the PAR values obtained are not necessarily representative of the PAR reaching the ocean surface from the sun.

**Known issues not represented in the QC flags**

There were also known issues with the LiCor sensor deployed on SOFS 1. Due to calibration issues the values recorded by this sensor were much lower than those recorded by similarly placed sensors on all other deployments. This problem is not caught by any of the tests utilised in this QC effort.

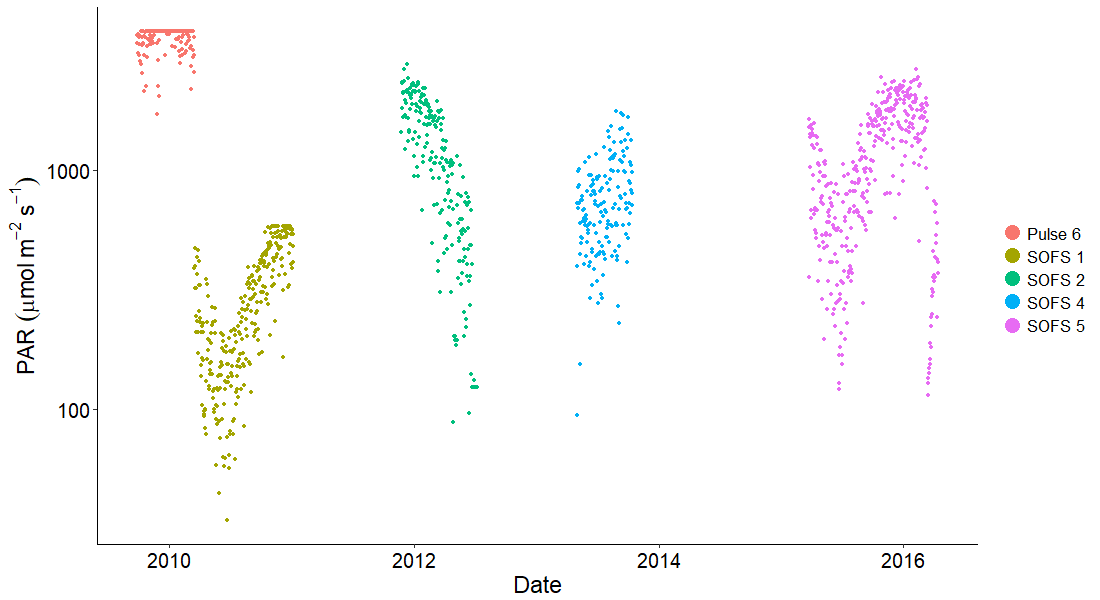
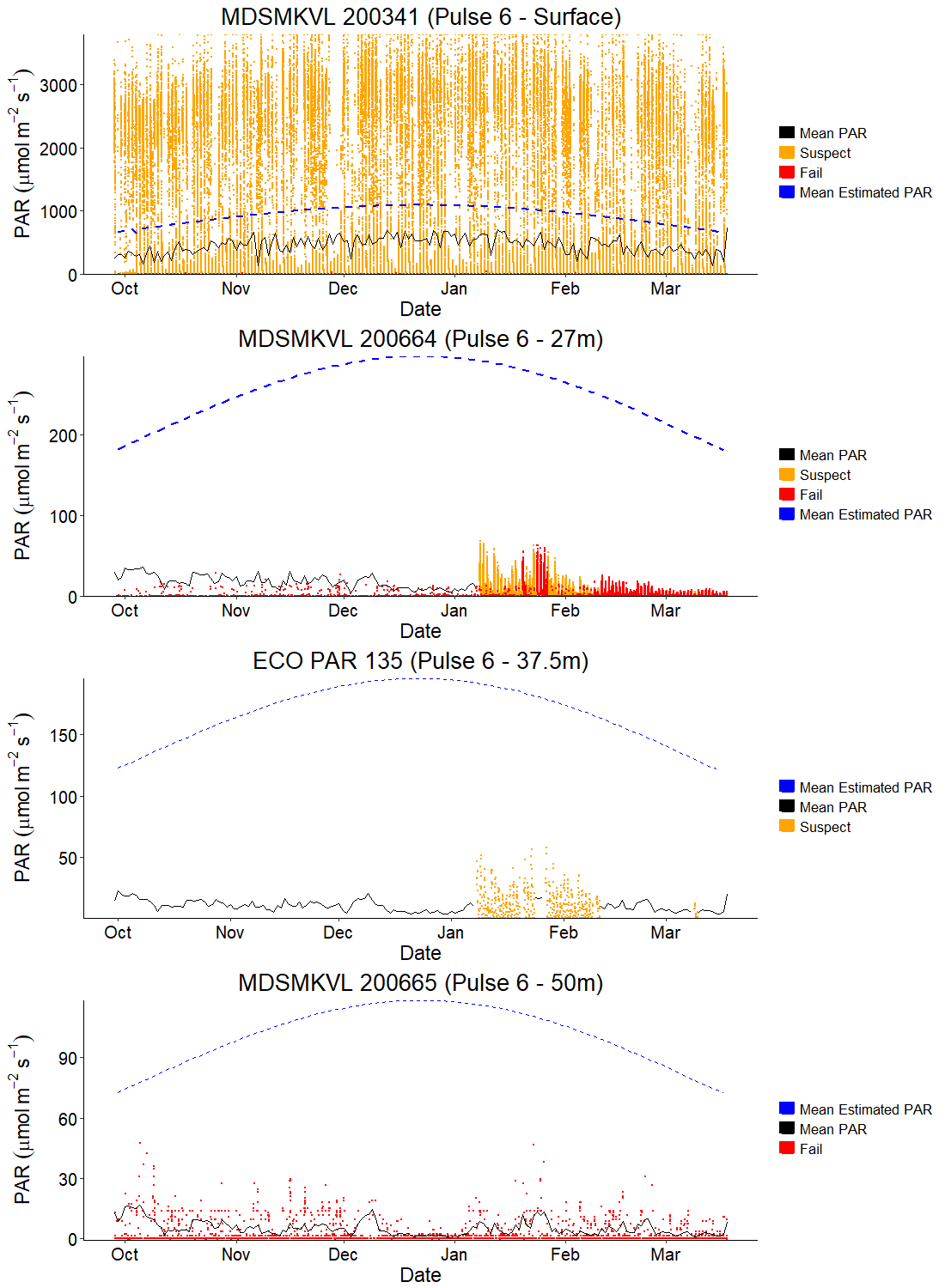


Figure 2. Daily maximum PAR values from surface sensors deployed at different times; note logarithmic scale on the y-axis. The maximum PAR in summer for the SOFS 1 surface sensor is significantly lower than the records from other sensors placed at the same position in different years. Also note that the spherical sensor on Pulse 6 produces consistently higher summer values than the cosine sensors on the SOFS moorings.

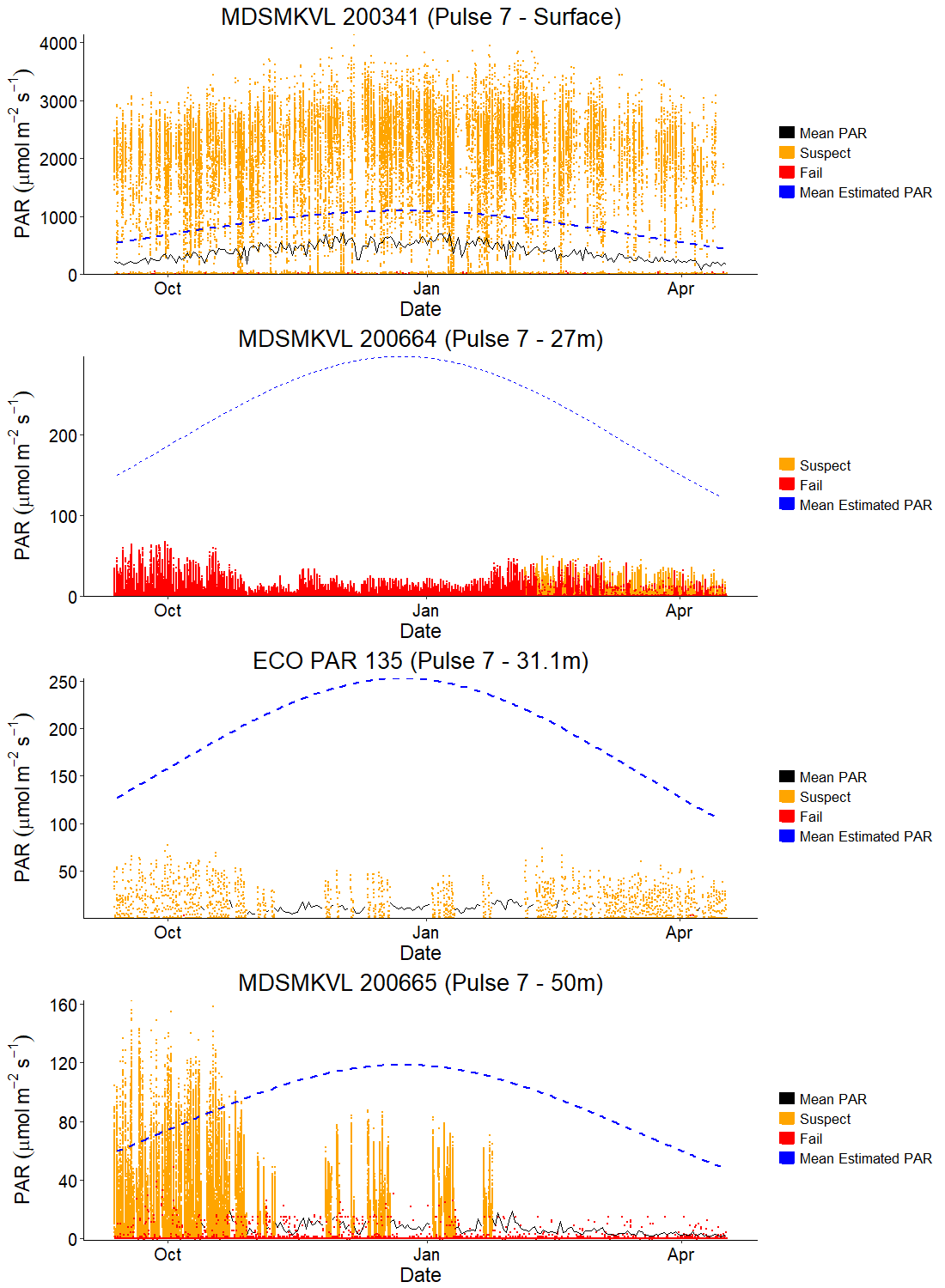
# Data Plots for Each Deployment

Below are plots of every deployment of each sensor, organised by mooring deployments. Data shown are daily mean PAR values calculated from data flagged as good (1) or probably good (2), with suspect (3) and fail (4) data shown as orange and red points respectively. The blue dashed line shows the daily means for the estimated PAR values calculated in the climatology test. Data series without any good or probably good points were plotted without a line for the daily mean.

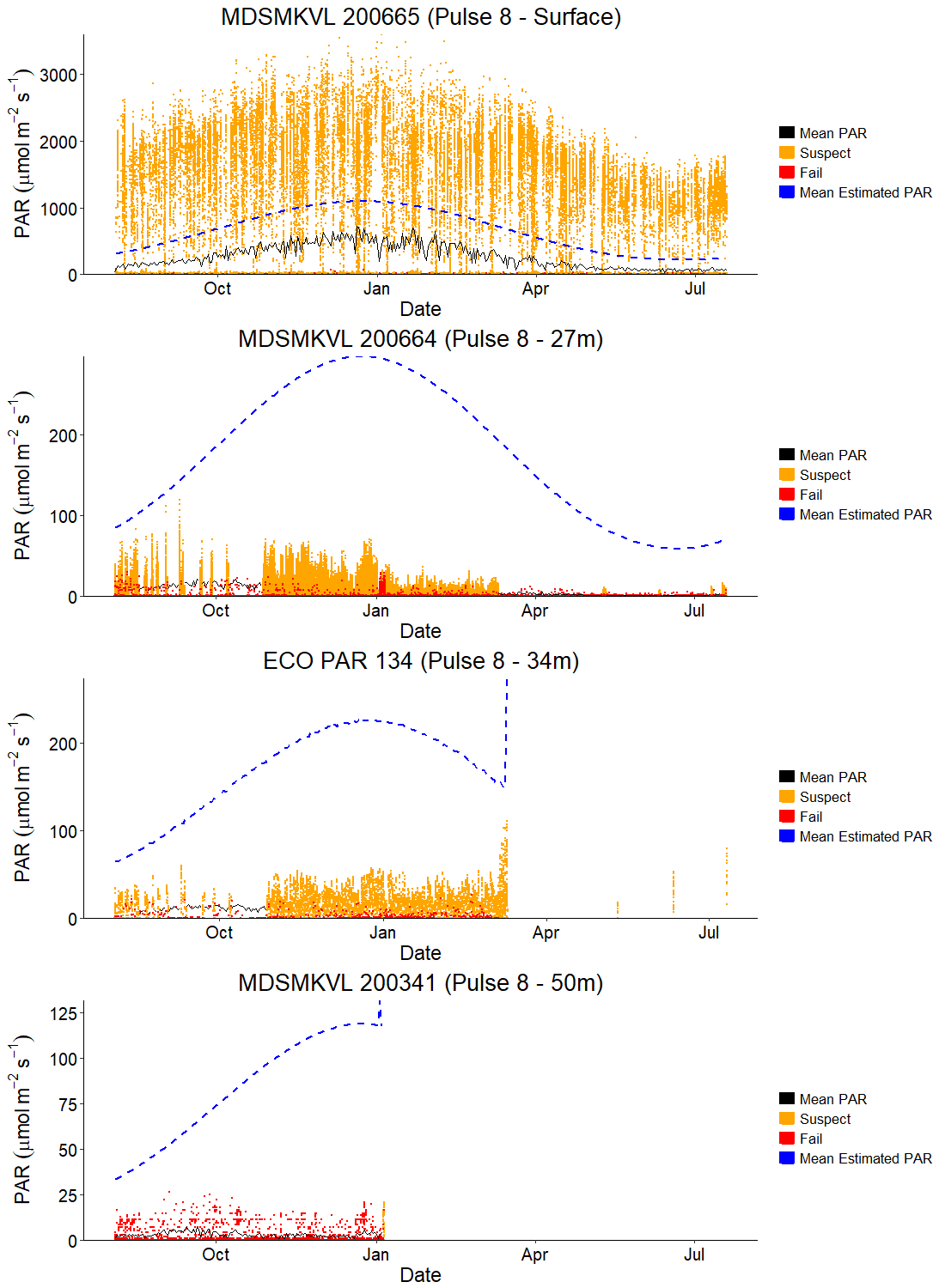
**Pulse 6**

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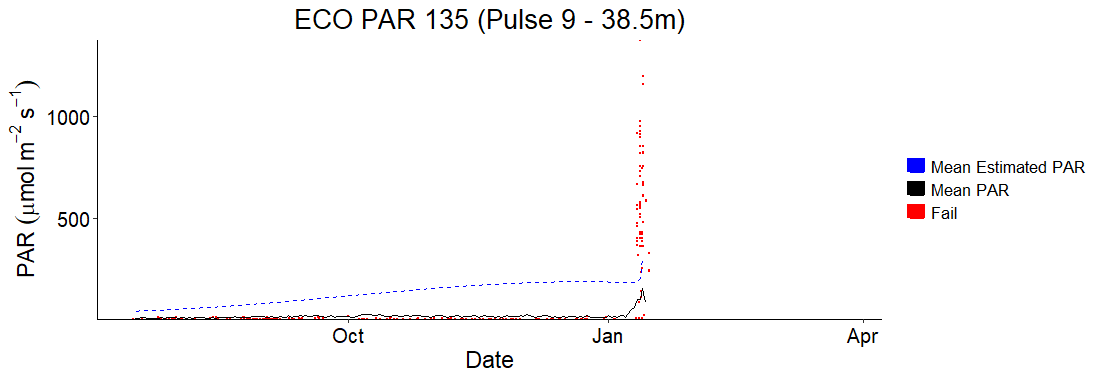
**Pulse 7**

****

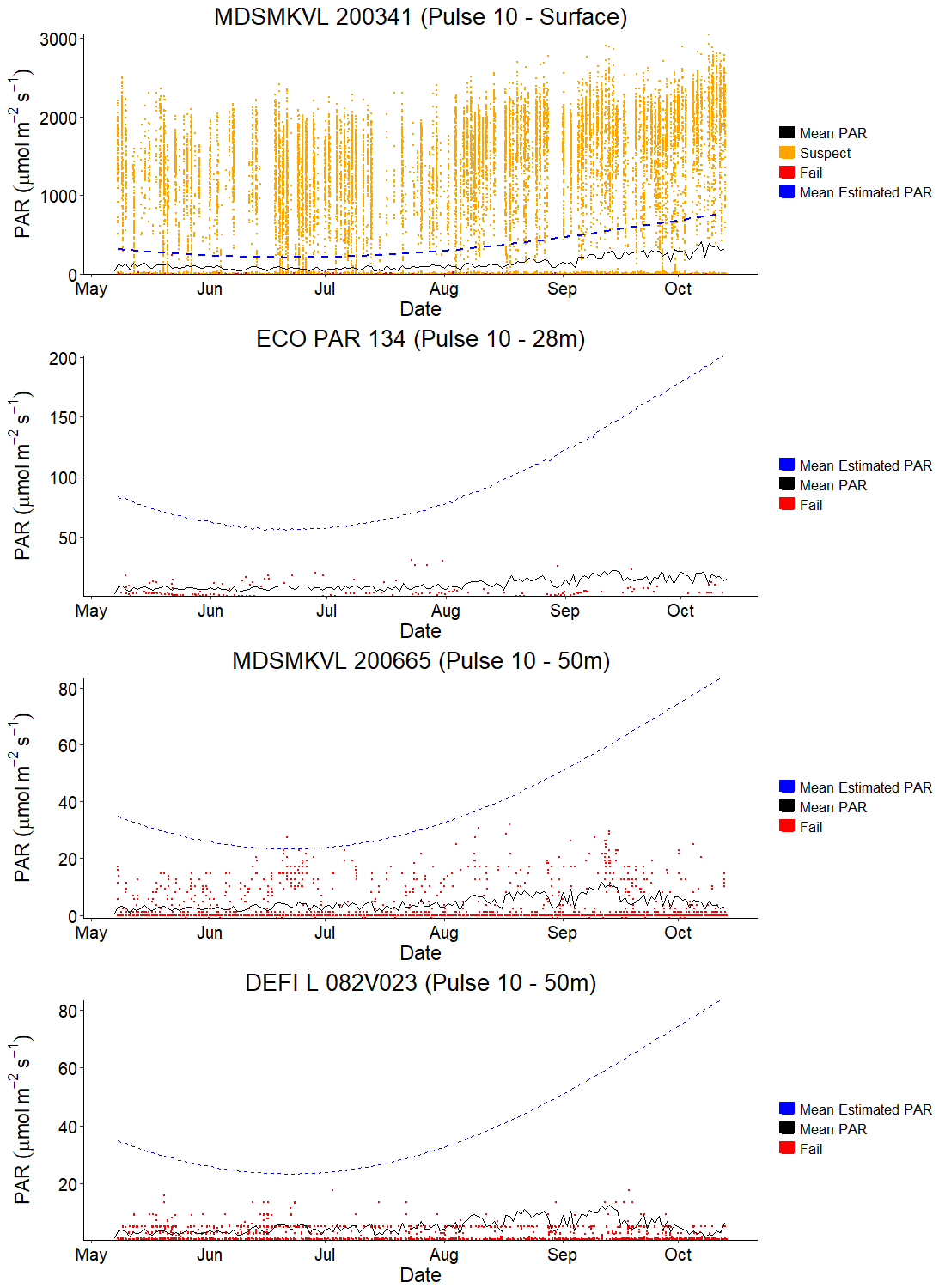
**Pulse 8**

****

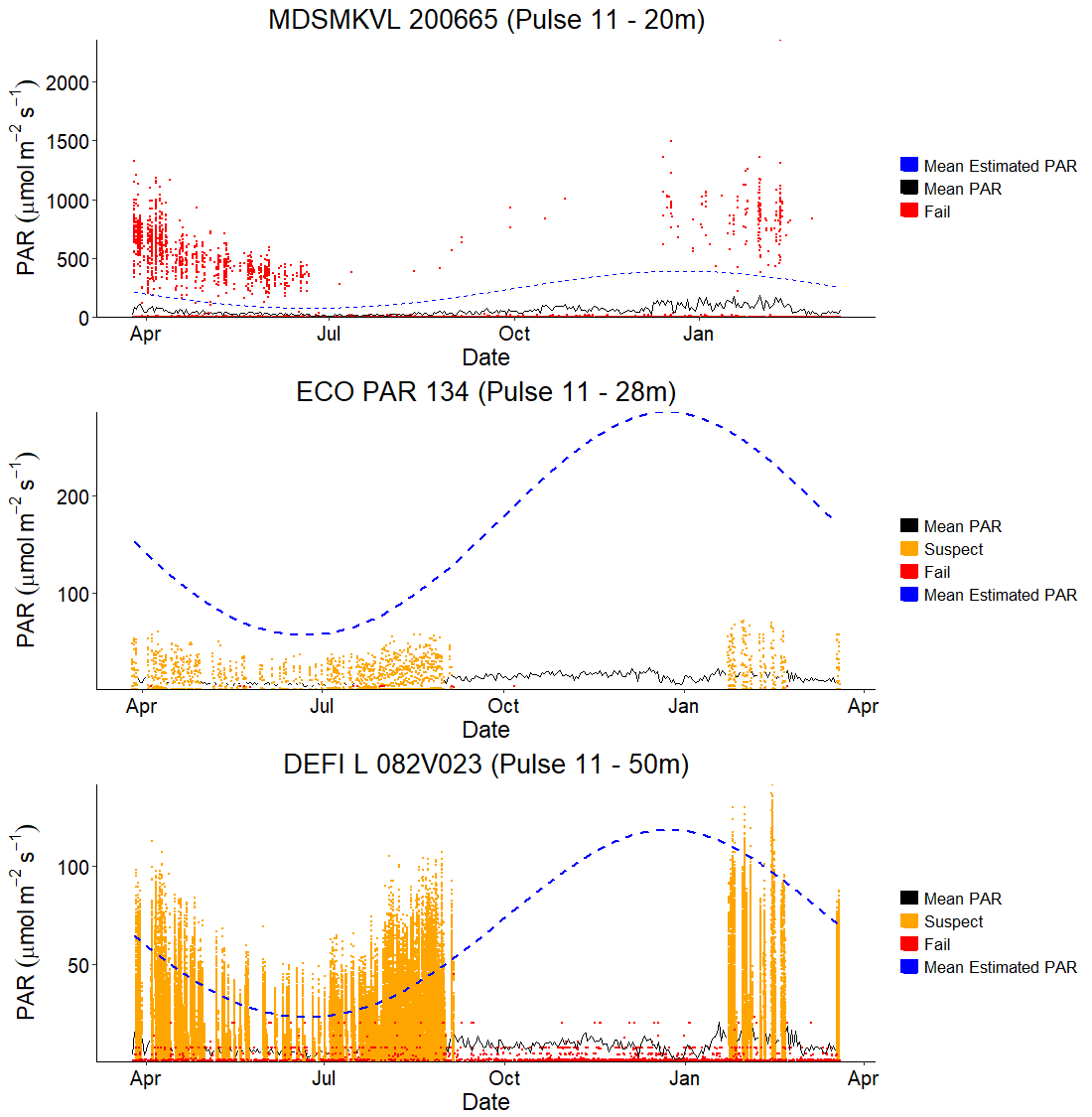
**Pulse 9**

****

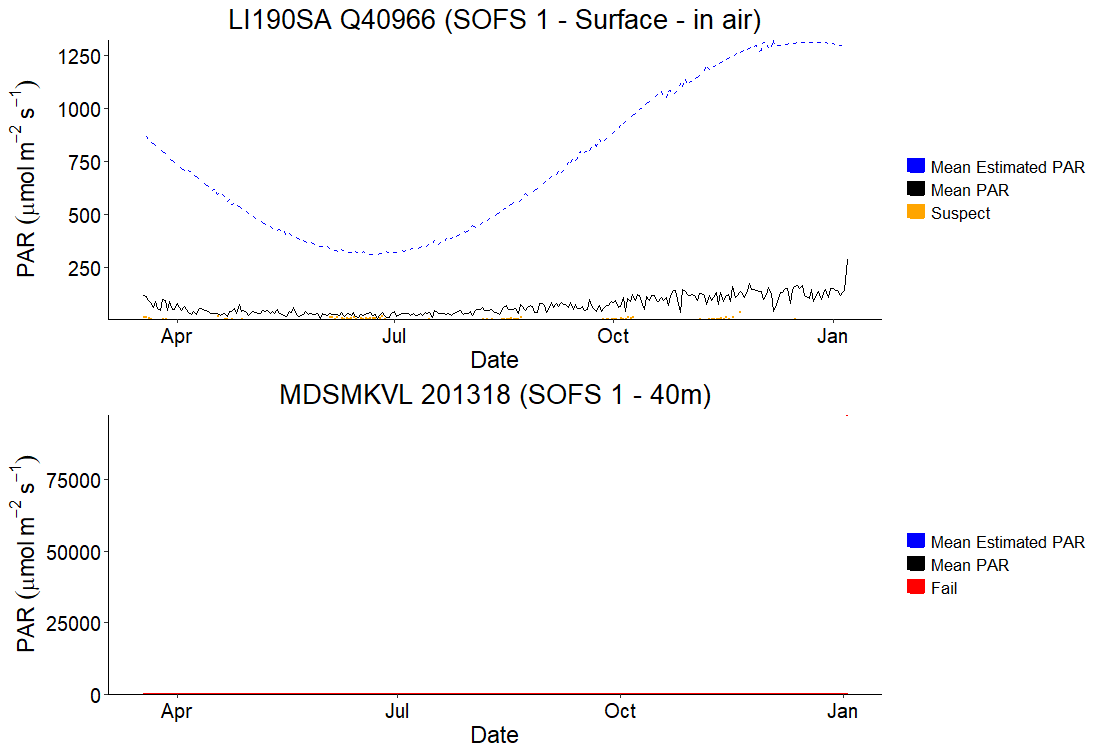
**Pulse 10**

****

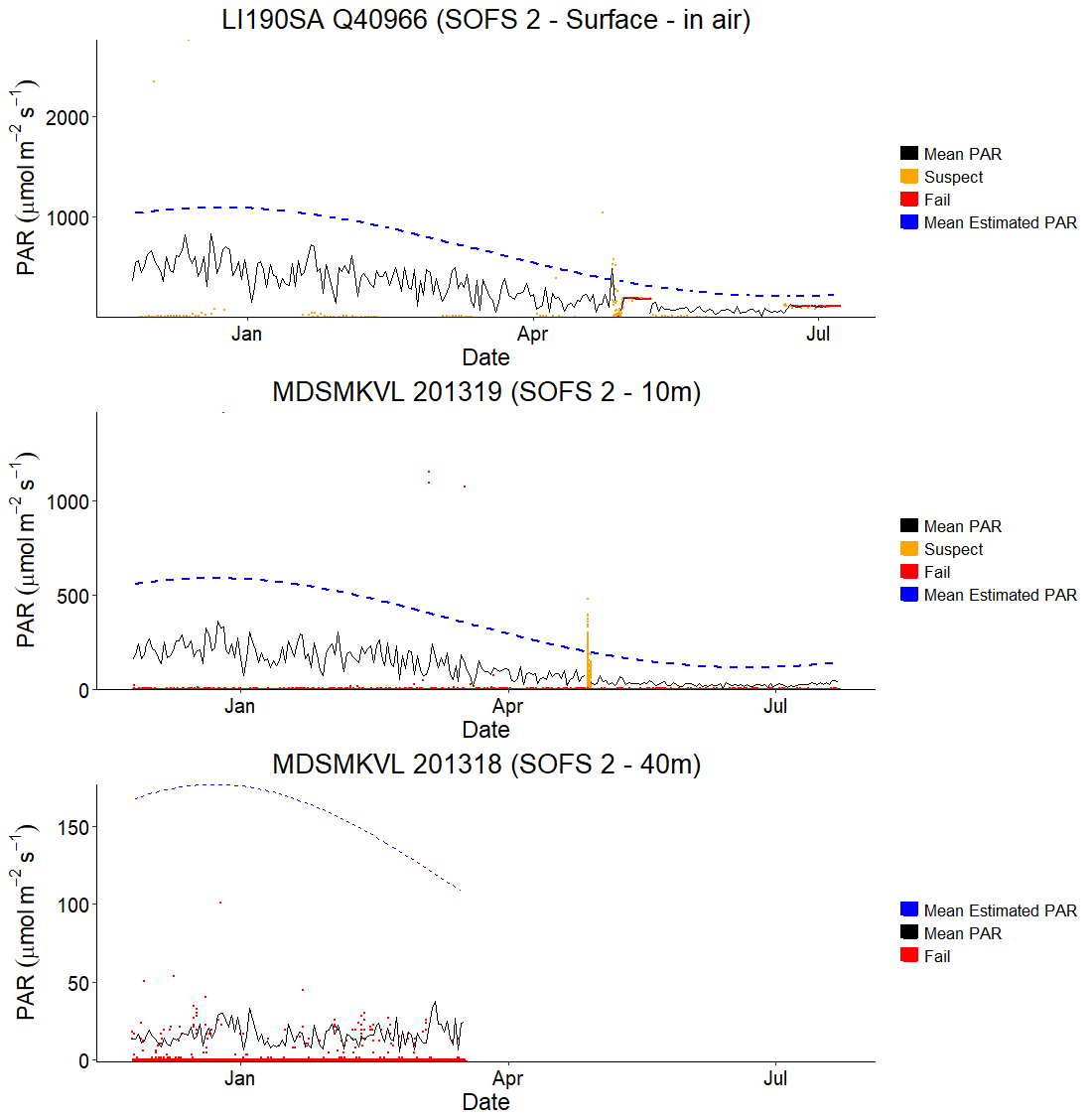
**Pulse 11**

****

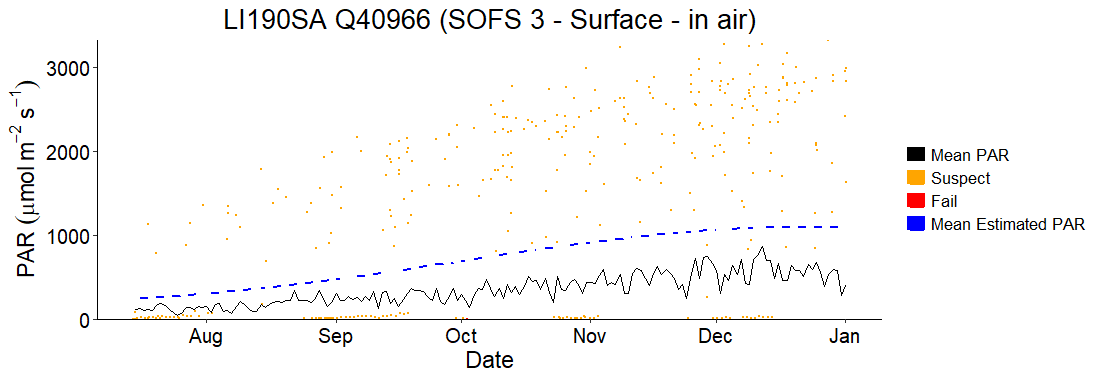
**SOFS 1**

****

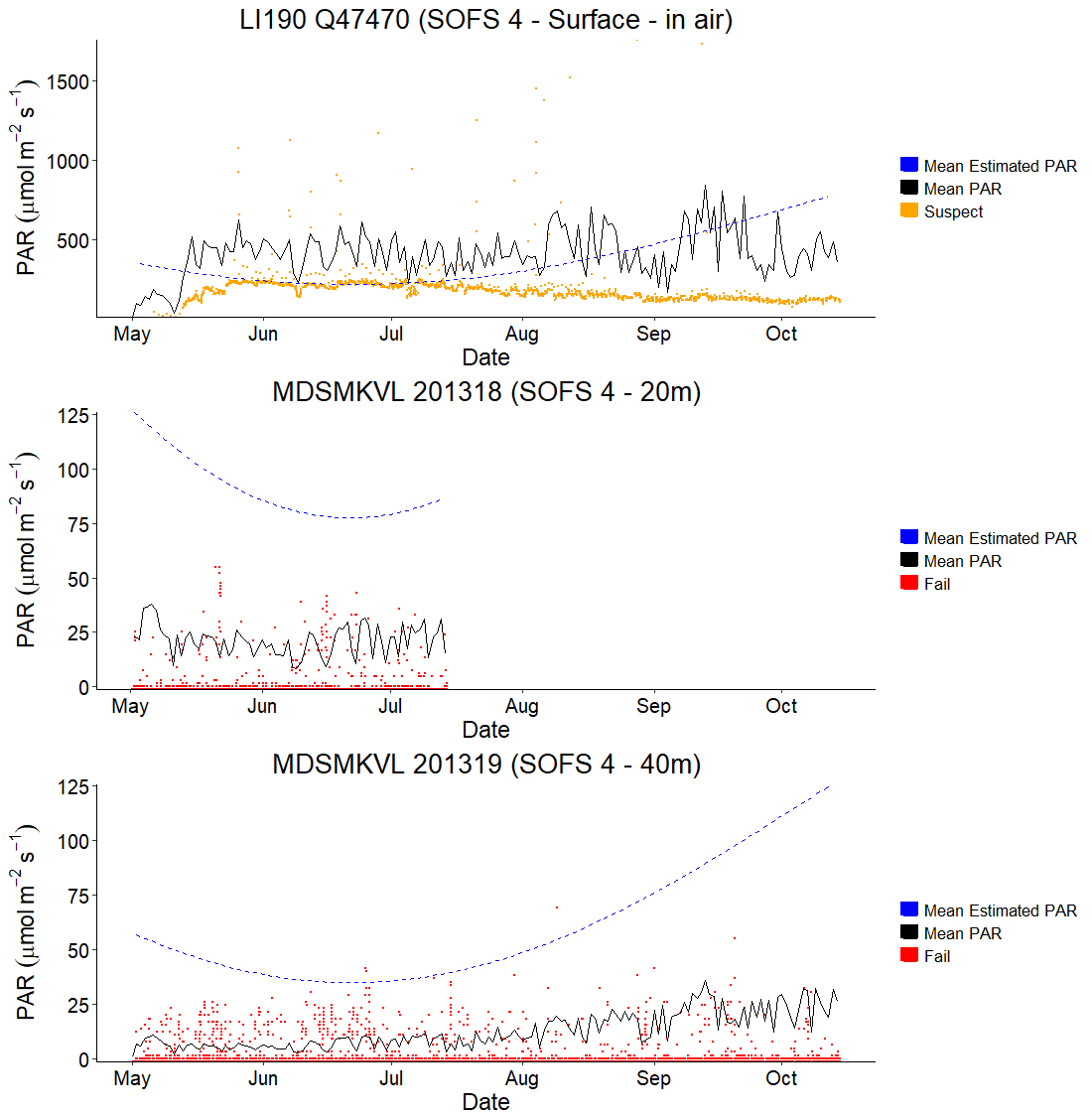
**SOFS 2**

****

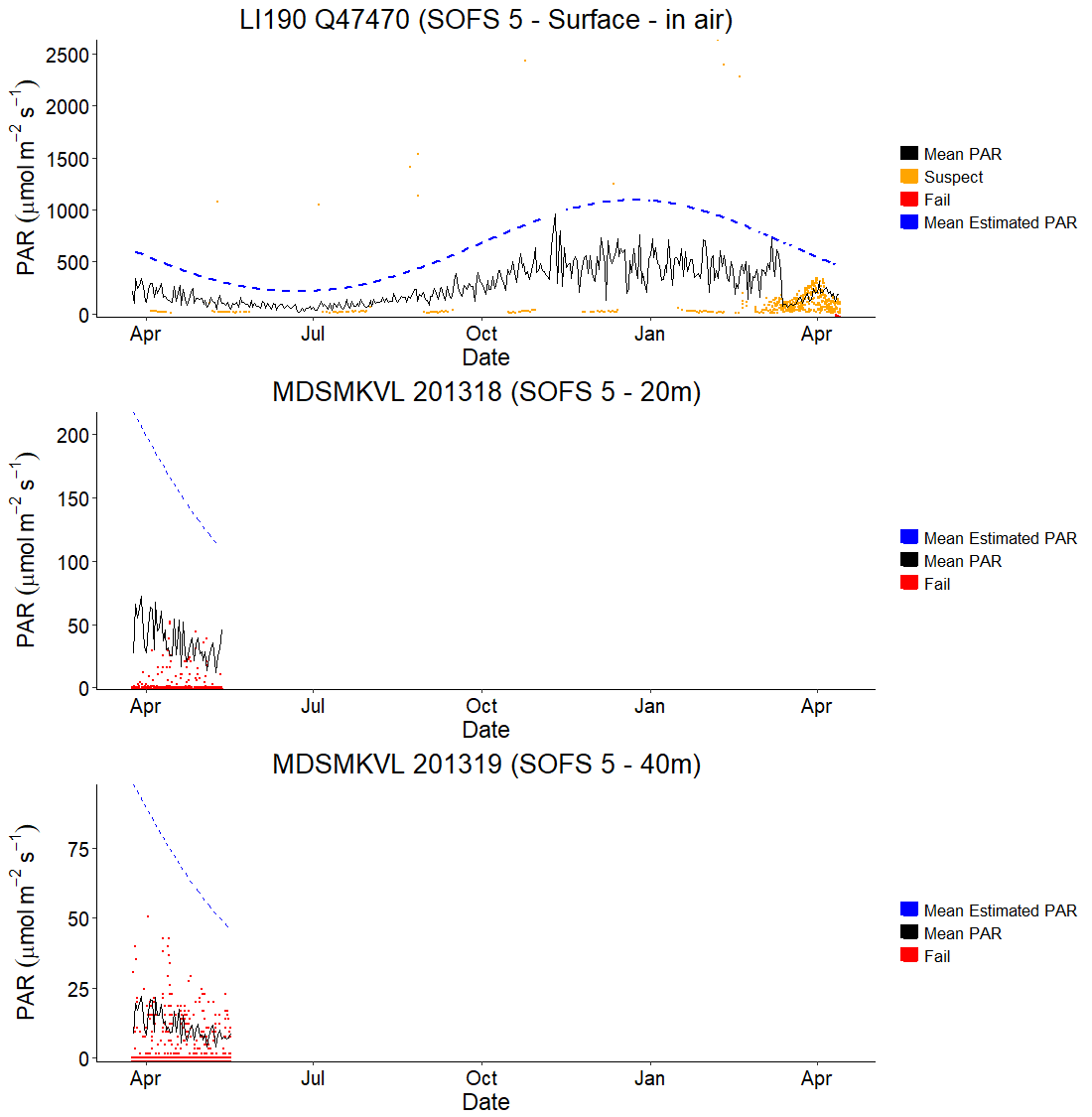
**SOFS 3**

****

**SOFS 4**

****

**SOFS 5**

****

Mean daylight hours radiation plots

NB with PAR = 4.57\* SWR (McCree 1972)



Pulse-6 PAR @ 0m is too high



SOFS-1 PAR @ -2.7m is too low.









Surface data

par = 4.57 \* sw



par = 2.115 \* sw



# 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.

# References

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

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.

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.

Names of R and Matlab files 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>

Sensor Calibration Sheets

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

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