

FIOX

The Fluorescence Box, a hyperspectral instrument for unattended observation of sun-induced chlorophyll fluorescence and reflectance.

Manual for Installation and Operation

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FLOX DESCRIPTION AND DIMENSIONS

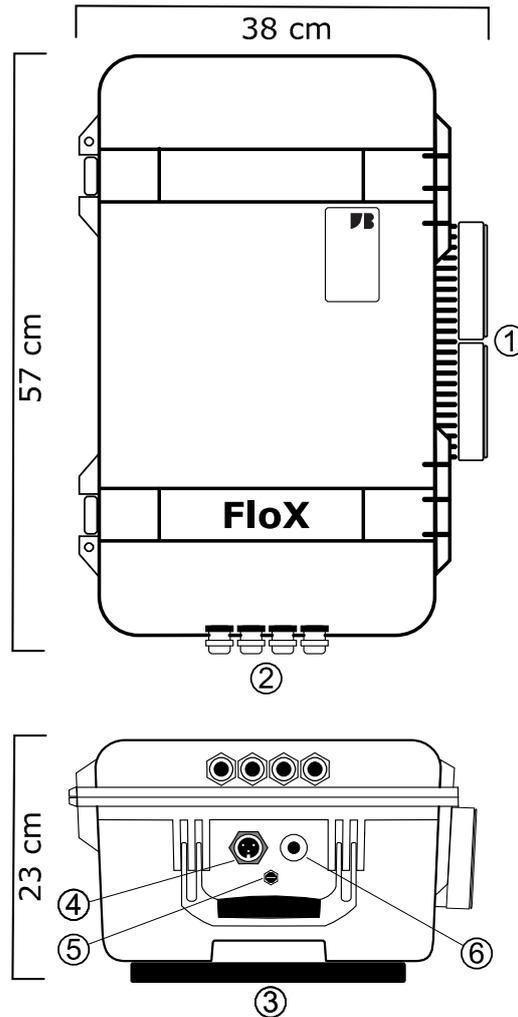
Last Update: 2019-06-19 FloX Firmware: 2.08

Included Items

1. FloX Spectroscopy System
2. AC/DC Wall Converter 100 W
3. USB Xbee Receiver
4. Spare Cosine Receptor
5. 32 Gb SD card (2 times)
6. Micro USB Cable
7. Power Plug (unassembled)
8. Flight Case for shipping

Dimensions

Figure 1 The FloX rugged case is based on the waterproof 1510 Pelicase®. The dimensions are the extents for transport, when the fibres are rolled inside the lid. When operated, the actual dimensions are exceeded by fibres leaving the fibre port (2) and the required airspace at the outer heatsink (1) for ventilation. The black handle (3) at the bottom of the instrument can be removed, including the wheels, revealing screw mounts, useful for permanent installation. At the front panel, the main power socket (4) is next to the blue signal LED (6). A multi-purpose connector (5) comes pre-installed and allows connection of special user add-ons.



FLOX DESCRIPTION AND DIMENSIONS

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Table 1 Parameters and features of the FloX as an automatic spectroscopy system for unsupervised operation

Operational Performance	Parameter Description
Automatic Acquisition	Fully autonomus measurement mode for unattended data acquisition
Manual Acquisition	User triggered measurement mode
Signal Optimization	Automatic adaption to varying light conditions
Dark Current Measurement	Accurate dark current determination for each measurement
Fast Measurements	20 seconds under bright sunshine 60 seconds in overcast conditions
Various Metadata	Internal Temperature, Internal Humidity, GPS Position, GPS Time
Measurement Display	LCD Display
Data Storage	SD card up to 32 gb (2 Years of measurements)
Power Supply	12V DC (10-14 V acceptable)
Power Consumption	20 Watt to 100 Watt at full cooling
Sleep Mode	User defined active and power saving time
Interface	RS-232 via cable and wireless

Table 2 Optical Parameters of the two internal spectrometer

Optical Performance FLUO	Value	Description
Spectral Range	~ 650 - 800 nm	Covering the O2A and O2B Band
Spectral Samling Interval (SSI)	~ 0.17 nm	1024 Pixels
Spectral Resolution	~ 0.3 nm	Full Width at half Maximum (FWHM)
Signal to Noise Ration (SNR)	~ 1000	
Dynamic Range	18 Bit	200.000 Digital Counts
Field Of View (FOV)	~ 180° Upwards; ~ 20° Downwards	Dual field of view optical path
Optical Performance FULL	Value	Description
Spectral Range	~ 400 - 950 nm	Covering the visible to near-infrared
Spectral Samling Interval (SSI)	~ 0.65 nm	1024 Pixels
Spectral Resolution	~ 1.5 nm	Full Width at half Maximum (FWHM)
Signal to Noise Ration (SNR)	~ 250	
Dynamic Range	16 Bit	
Field Of View (FOV)	~ 180° Upwards; ~ 20° Downwards	Dual field of view optical path

FLOX OVERVIEW AND OPERATION

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Overview

The FloX is a spectroscopy system for the unsupervised retrieval of Sun-Induced-Fluorescence (SIF) and spectrally resolved reflectance. The instrument consists of two high performance spectrometers contained in a temperature controlled compartment. One fine resolution spectrometer (FLUO) covers the range from 650 nm to 800 nm observing the SIF signal within the O₂A and O₂B Fraunhofer Absorption lines. The second spectrometer (FULL) covers the range from 400 to 1000 nm. Each spectrometer measures the down welling irradiance and the upwelling radiance using two optical fibres. A rugged weatherproof case and an autonomous acquisition protocol including data storage allows continuous observation of plant canopies over long periods.

Unsupervised Operation

The instrument requires a careful setup to achieve reliable measurements (ref. PERMANENT INSTALLATION & MOBILE USE). When power (DC 12 V 100 W) is provided, the instrument switches on by a press on the On button. If the FloX is inside the specified operating hours an initialisation and self-check runs prior to the automatic acquisition cycle. The measurements are performed according to the parameters set in the config.txt contained on the instruments SD card (table 1). When the time interval between consecutive measurements has passed a new cycle begins by optimising the integration time for the FULL spectrometer upward and downward channel. Subsequently one measure of the down-welling irradiance (WR1), the up-welling reflected radiance (VEG) and again the down-welling irradiance (WR2) is taken. After this, one dark spectra is acquired with the upward integration time (DC_WR) and a second one with the integration time

of the downward (DC_WR). All spectral data (1024 pixel per spectrum) is saved to SD card (ref. RAW DATA) and streamed via serial if this option is active (ref. SERIAL INTERFACE). The FULL cycle is now finished and followed by an identical measurement protocol of the FLUO spectrometer. After that, the FloX will pause till the next measurement interval is reached. Along with spectral data, various metadata is saved in the header of each measurement cycle. Among these is the time of the measurement as local and GPS-UTC as well as GPS position and internal sensors for temperature and humidity. If the Off hour, specified in the config.txt is reached, the instrument will enter power saving mode until the On time in the next morning. During the sleep mode no spectral measurements are performed. The power requirement will drop from 20-100 W during operation to less than 1 W during sleep. FloX will keep measuring as long as power is available and there is space on the SD card. If the power fails, the FloX will recover as soon power is restored. A 32 gb SD card has capacity for about 2 years of spectral data.

Warning Notes

Do not bend the optical fibres below a radius of 8 cm. A lower radius will alter the calibration and a narrow bending can break the fibre.

Only remove the SD card while the instrument is off. Removing the SD card during operation can result in data loss.

If the instrument is used outside operating hours, it will not switch on. The outside blue LED will blink periodically to indicate sleeping mode. Operating times can be user defined via config.txt or serial connection.

FLOX OVERVIEW AND OPERATION

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Figure 1 Light reception of the cosine receptor of the upward looking fibers with a hemispherical field of view. The downward looking bare fibers have a field of view of 23°.

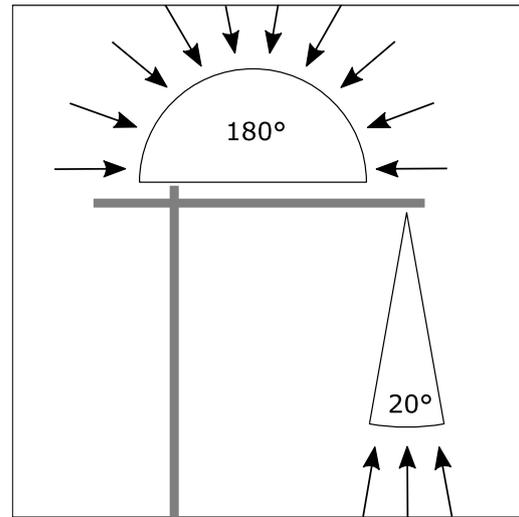


Figure 2 Major steps of the unsupervised and manual acquisition protocol. Tripple arrows indicate user interaction by pressing the button during startup to induce manual measurements, triggering measurements via the button or activating serial data stream.

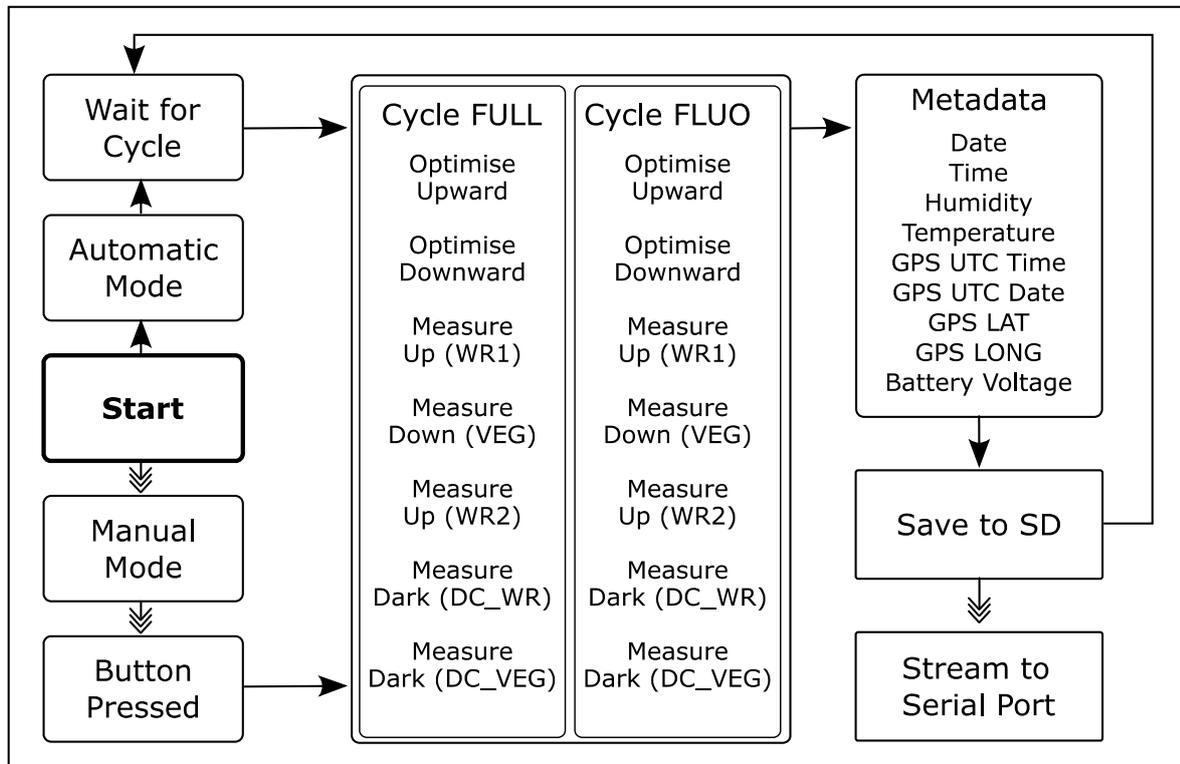


Table 1 content of config.txt

config.txt Label	Standard Value	Description
Max IT	4000 ms	Maximum integration time for FLUO
Interval	0 s	Interval between measurements
Serial Resolution	20 Pixel	Pixel Density for a Serial Stream
Serial Stream	0	Various serial live output is enabled
Serial Transfer	1	Data is sent after each cycle
FLED Cycle		Special User Function
FLED Power		Special User Function
Averages FLUO	1	Allows averaging of multiple spectra
Averages FLAME	1	Allows averaging of multiple spectra
Switch on Time	8	Time in hh to start the instrument
Switch off time	20	Time in hh to shutdown the instrument
Cooling mode	1	1 = only on while measuring; 2 = always on
Low Voltage Shutdown	10	Voltage threshold to shutdown

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The field of view

Prior to setup the FloX over a canopy, considerations about the homogeneity inside the field of view are essential. A low vegetation type (e.g. grass) with a homogenous pattern yields useful data from low observation heights. Larger, more coarse vegetation (eg. corn or shrubs) or even forest will require a larger field of view, thus a higher observation position. The opening angle of the downward looking fibre is 23° which leads to recommendations given in Fig 1. Further, consider that the 3D canopy architecture or rows of managed vegetation (e.g. vineyards) can have a significant effect on the diurnal pattern of the retrieved fluorescence signal. The tower itself should be placed north of the field of view to eliminate shadows of the structure inside the observed vegetation. A nadir setup reduce these effects and generates measurements comparable to airborne, satellite and other instruments.

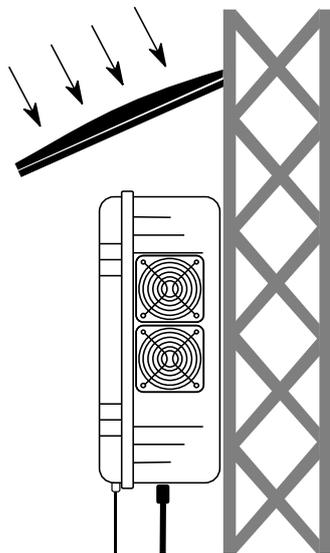


Figure 2 FloX installed at a large tower including a roof against solar radiation and rain. Fibre ports and power sockets are facing downwards.

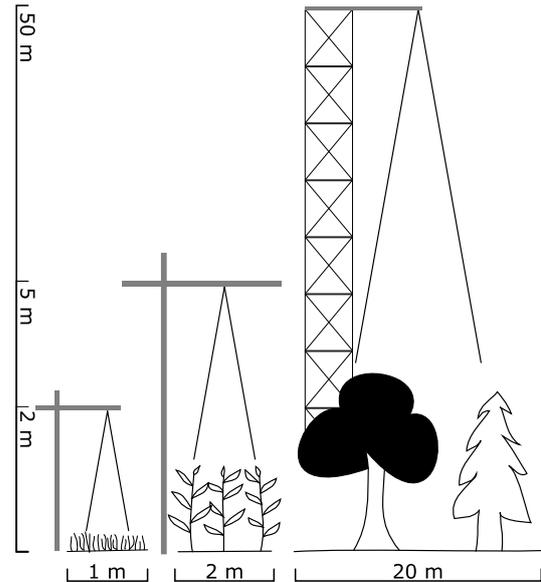


Figure 1 Typical tower setups for grass, corn and forest with reasonable size estimations based on working setups. Drawing not to scale.

Tower type and setup

The necessary height of the installation drives the tower type. Towers up to a size of 5 m are available in relatively easy to deploy forms and can be erected within a day (Contact JB for tower types). Larger structures may already be available at the research site or require bigger efforts in construction. The FloX usually has a fiber length of 7 m (longer fibers are an option). If the instrument should remain accessible close to the ground the overall height of the tower is limited to about 5 m. On a bigger tower, the instrument may be attached to the tower directly at an elevated position. The weight of the instrument (18 kg) and additional cables, optics and accessories should be well within the limitations of the support under all environmental conditions (e.g. wind or snow). To attach the FloX directly to a tower, the black carrying case attachment can be unscrewed revealing a number of

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mounting points. Install the FloX with fiber ports and power plug facing downwards. Lead the downward looking fibres above the vegetation of interest and level the optics nadir. Lead the upward looking fibres with the cosine receptors to the very top of the tower and guarantee that the observed hemisphere is completely free from obstacles. Level the cosines. Using a bird and dust protection system is recommended to keep the sensitive upward looking optics functioning for long periods. Do not bend the optical fibres below a radius of 8 cm. The FloX has a durable weather-proof casing and can withstand extreme environmental conditions. However it is recommended to shield the instrument from direct sun to reduce the necessary cooling power (Fig 2). This is essential in hot environments to ensure valid measurement conditions. The FloX will switch off when the internal temperature exceeds 55°C. Various temperature sensor allow to track the temperature of the instrument. To seal the instrument, the 4 optical fibres are fixed using the black element of increased thickness in the ending part, inserted in the fibre ports and tightly screwed. To test whether the instrument is fully sealed, apply force to the lid. If the sealing is good, a hissing sound will appear at the overpressure vent and the lid will not unbend, since no air can enter the case anymore. However it's still good practice to leave a bag of drying agent in the case (e.g. silica). Humidity of the instrument can be tracked via two internal sensors. Remote data download can be realized using the SERIAL INTERFACE.

Power

The FloX is rated 100 W peak power and requires a 12 V DC input. However the average consumption is usually lower and mostly driven by the outside temperature and the need for cooling. Running the FloX from

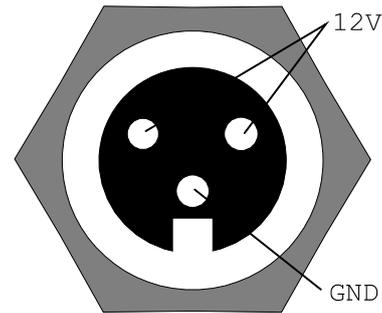


Figure 3 Electrical layout of the power socket of the FloX instrument, mounted to the front wall.

grid power using the included AC/DC adapter ensures complete datasets. In off grid scenarios a solar driven setup including a large buffer battery is possible and can be provided by JB. However this can lead to data gaps during very hot or very dark weather periods. To allow a battery driven operation, the FloX internal DC/DC converter allow an input voltage range of 10-14 V. Higher or lower voltage will lead to a shutdown of the instrument. Further, the FloX is polarity protected. To implement the instrument in existing 12 V power grids, an additional plug is included. Refer to Figure 3 for pin layout of the plug.

Safety

During all installation and operation take precaution for your own safety. Especially do not climb unsafe towers and take precaution if AC wiring is performed. Ask trained personnel or JB whenever you're in doubt on a safety question.

Environmental hazards

If the tower of the FloX is the highest structure in the surrounding, it needs a lightning conductor. Eventually use fences to keep humans or cattle out. The use of a webcam watching the instrument and the vegetation is very useful for scientific and monitoring purpose.

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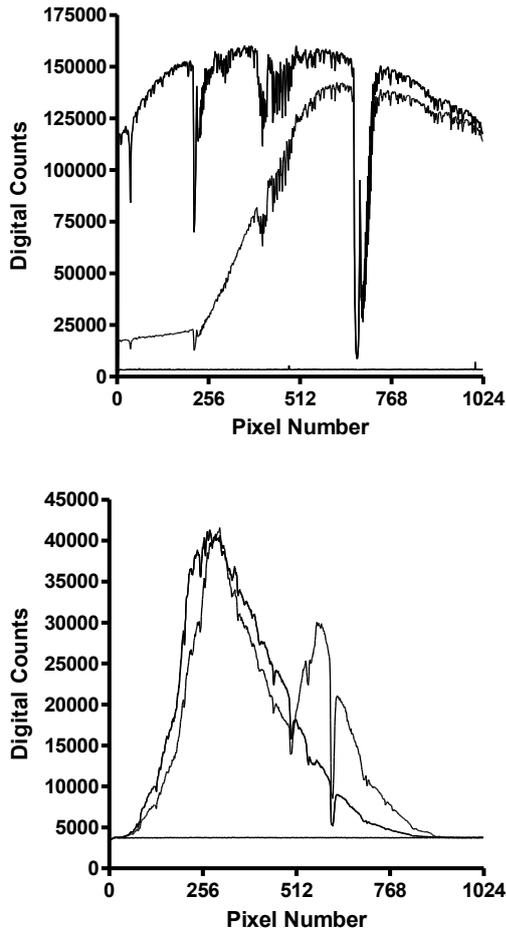


Figure 1 Top: typical spectral data as stored in the FLUO measurement file. Bottom: typical spectral data as stored in the FULL measurement file. The spectra show the upward and downward looking channel raw data (counts) and the recorded dark current for each channel.

SD Card Content

The FloX uses a standard SD card with a size up to 32 gb as data storage. If no SD card is inserted or the SD card is full, the instrument will not store data. In the root folder of the FloX, the "config.txt" is located (see *Overview and Operation*). In an empty SD card, the FloX will generate a new config file with standard parameters. In the root folder, the instrument creates a folder for each day it was active. This folder is labelled after the FloX clock time date (YYMMDD). Inside this folder, the FloX creates

two files containing spectral measurements. The file storing the FULL spectra begins with "F" followed by the time, the instrument was switched on (hhddmm). The file type is a human readable *.CSV using a ";" as delimiter. The file storing the FLUO spectral is named just after the switch on time (hhddmm). Both files can be opened via a generic text editor and many other software suits. It is good practice to make a backup of the SD card content whenever the field site of the instrument is visited. Typically one file for each spectrometer is generated each day. If the instrument is switched on several times a day, (eg. solar power low) multiple files can appear within the same folder. To limit the file size, a new file will be generated if 1000 cycles are exceeded. A nightlog file shows internal measurement parameters, to track the conditions during night.

Raw Data Structure

The spectral data inside the measurement files is raw data, thus digital counts are stored. To convert these digital counts to actual physical values (eg. radiance) and to calculate fluorescence or other results, a post-processing is required (see POST PROCESSING). Most users are interested in the processed products, however the structure and content of the data files is explained in the following. One measurement cycle is stored within 6 lines, whereas the first line is the header containing metadata. In line 2-6, the spectral data is given in the order: 1 upward looking (WR1), 2 downward looking (VEG), 3 upward looking (WR2), 4 dark current of WR, 5 dark current of VEG. Since the upward looking and downward looking channels have different integration time to achieve an optimal use of the dynamic range, they may be affected by different dark currents. This is accounted for by acquiring two dark current

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measurements with the two different integration times. Further the instrument measures twice the upward looking channel to quantify the stability of illumination during the measurement. Both spectrometers store 1024 pixels for each spectrum. A typical spectral data for FLUO and FULL is given in Figure 1. The metadata within the header of each measurement contains essential data for processing, such as integration time or the actual time of the measurement. Further it contains additional sensor values such as temperature and humidity

measures to assess the instruments operational state. An implemented GPS sensor is used whenever GPS signal is available to also store UTC time and date as well as the approximate position of the instrument. The header of the two spectrometers differs slightly and special user variables may be appended in the end of the header line.

Table 1 Metadata of the FLUO header line. Field indicates the position of the described value in the semicolon separated line.

Field	Label	Unit	Description
1	Cycle Number		Increments with each measurement cycle
2	Date	YYMMDD	Current Date, User Defined
3	Time	hhmmss	Current Time, User Defined
4	Mode	auto or manual	Indicates the mode of operation
6	IT_WR	µs	Integration Time of the upward looking channel
8	IT_VEG	µs	Integration time of the downward looking channel
10	Cycle Duration	ms	Time that the measurement cycle took
12	FLUO frame temperature	°C	Temperature of the spectrometers housing
14	FLUO CCD temperature	°C	Temperature of the spectrometers CCD
16	Mainboard temperature	°C	Temperature of the main controller
18	Chamber temperature	°C	Temperature of the spectrometer compartment
20	Mainboard humidity	%	Humidity at the main controller
22	Chamber humidity	%	Humidity inside the spectrometer compartment
23	Firmware and ID		Running firmware and Device Identifier
25	GPS Time UTC	hhmmss	Time as retrieved from GPS satellite
27	GPS Date UTC	YYMMDD	Date as retrieved from GPS satellite
29	GPS Latitude	decimal degree	Latitude from GPS
31	GPS Longitude	decimal degree	Longitude from GPS
32	Voltage	V	Level of supply voltage
34	gps_CPU	ms	CPU Time of the last GPS timestamp
36	wr_CPU	ms	CPU Time of the WR1 measurement
38	veg_CPU	ms	CPU Time of the VEG measurement
44	Spectral Averages		How many spectra have been averaged

FLOX SERIAL INTERFACE

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Introduction

Extending the standard unsupervised operation, the FloX provides an interface for advanced control. The interface is based on the common RS-232 protocol and accessible either via micro USB socket or wireless via XBee modem, both appearing as emulated COM port on a host computer. This means a direct serial connection can be established by plugging a micro USB cable to the FloX' socket next to the SD card and any computer regardless of the operating system. The same connection is enabled wireless up to 100 m range using the Xbee modem, included in the instrument. Connecting this with any given computer will open the same serial channel enabling extended commands and data download. On most operating systems, the drivers for FloX and Xbee modem will install automatically (contact JB to get troubleshoot).

Serial Operation

To activate the serial connection, first switch on the FloX and second connect either USB cable or modem to the computer. Make sure a new COM port appears in your device and note the number or identifier of this COM

port. Use any available interface software to open the COM port (eg. Termite) with a Baudrate of 57600. Ensure the software will append a newline character "\n" to submitted ASCII commands. In automatic operation, the instrument will stream the collected data via the serial port after each measurement cycle. If the serial connection was properly established a data stream will be received periodically from the instrument. Between cycles, the instrument will wait for serial commands. To stop automatic measurements and switch to manual mode send a "C" via the serial terminal. This will command the FloX to halt measurements after the current cycle is completed and then send a list of possible serial commands. Commands are single or double case sensitive letters. Some commands require a following number, which is given after the command, separated with a blank. All commands will send a reply or lead to a measurement action of the instrument. Invalid commands are ignored. Note that a couple of commands will alter the instrument settings and thus change the content of the config.txt, being valid after FloX reboot. Changes can also be made directly to the config.txt using a text editor.

Table 1 Serial Commands for file handling and data transfer

ASCII Command	Standard Value/Example	Description
ff		Send the file folder structure of the SD card
f1		Send the current FLUO raw file
f2		Send the current FULL raw file
fn		Send all files acquired today
fd YMMDD	fd 190203	Send all files acquired at the specified data
fc		Send calibration file
ss	Off	Toggles serial stream, providing extended feedback *
S x	S 20	Defines the resolution of the serial stream spectra *
st	On	Toggles serial data transfer, to send data after cycle *
DM	DM 2	Set the power mode of the optional embedded computer * (0=always on, 1=on during day, 2=only once after off)

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ASCII Command	Standard Value/Example	Description
O		Optimise integration time without measurement
M		Measure without optimising integration time
m		Measure with optimizing. Equivalent to normal cycle or pressing the button in manual mode.
I1 x	I1 100	Sets the FLUO integration time to x ms (10 ms to 10s)
I2 x	I2 100	Sets the FULL integration time to x ms (10 ms to 10s)
IM	IM 4000	Sets the FLUO maximum integration time to x ms *
a1 x	a1 1	Sets the number of averages for the FLUO *
a2 x	a1 1	Sets the number of averages for the FULL *
i x	i 60	Sets the interval between measurements * to x s (range 0 s to 3600 s)
G		Send the current GPS data
c		Send the config.txt settings
T		Set date&time. You'll be asked to set YY, MM, DD, mm, ss
V	V 10.0	Set the threshold for low voltage shutdown. * Chose this value to protect the power supply battery.
On hh	On 8	Sets the starting hour to hh *
Off hh	Off 20	Sets the shutdown hour to hh *
FLAME	Full range active	Toggles the FULL spectrometer. If deactivated, the FULL cycle will be skipped

Table 2 Serial Commands for instrument control. Note, that beyond the given list, a number of additional commands exist for calibration and special purpose.

Remote Data Access

If a FloX instrument is installed in a remote area without direct access data can be downloaded using the serial interface. The actual technical implementation is site dependent but will require a computer with internet access. This computer is connected either via cable or Xbee modem to the FloX. data can be streamed directly while measurements are running with serial transfer (st) enabled or retrieved in the evening (fn). The computer needs to log this serial stream to the harddrive (eg. Termite->Logfile). A download of this daily logfile can be handled via scripts or additional programs. The FloX

can be equipped with an internal embedded computer featuring an interface software to download the data. This solution is preferred, since the FloX can activate this computer only once per day (DM = 2) to push the data to a server. This will save a maximum of power. The embedded computer however requires integration into existing internet structure via wireless LAN or Ethernet. A mobile network internet access is possible but reliability is case dependent.

Note that Remote Data Access is under development and will expand in the near future supporting FTP upload and other options.

FLOX DATA PROCESSING

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Overview

The FloX data processing is entirely based on the open source R software (R Core Team, 2017). The core functions of the data processing are contained in two R packages (FieldSpectroscopyCC and FieldSpectroscopyDP) openly available on GitHub platform at <https://github.com/tommasojulitta> and released under the licence GNU v3.0. The Graphical User Interface is provided to FloX customers as an R script to facilitate the analysis of the data collected, although the source code is available to JB customers and potentially adaptable to user's needs.

Processing chain concept

The concept behind the processing of the data follows a specific workflow:

1. Reading of input files (raw data, see *Raw Data*)
2. Conversion of raw data to radiance data (using the JB provided calibration files)
3. Calculation of apparent reflectance factors
4. Spectral convolution on Incoming and reflected radiance if specified by the user
5. Smoothing of the reflectance factor according to smoothing spline (degree of freedom to be defined by the user)
6. Calculation of Reflectance based Spectral Vegetation Indices (SVIs)
7. Sun Induced Chlorophyll Fluorescence retrieval
8. Calculation of QA/QC routines

Graphical User Interface

The FloX processing GUI runs on Windows OS (XP, 7, 10). It requires R software (version 3.3.2 and later) and RStudio to be installed in the pc. The following steps need to be followed in order to launch the GUI: 1) Open R studio; 2) Browse to code, source code; 3) Select the GUI.R to be processed (e.g. GUI_V13.R).

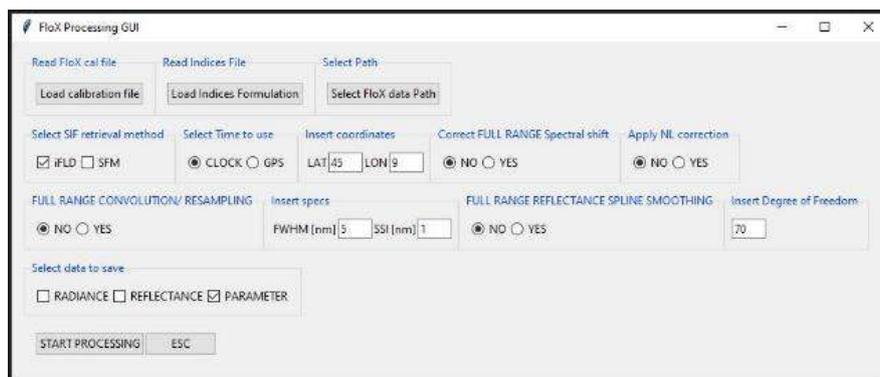
On first usage of the GUI the dependencies on other R packages are loaded. Before proceeding with data processing check if all the dependencies are loaded correctly and no errors appear.

FloX Processing GUI appears as reported in Figure 1.

The user is requested to make the following actions:

- 1) Load the calibration file
- 2) Load the indices file
- 3) Select the path where the FloX data are stored
- 4) Select the method to retrieve fluorescence
- 5) Select the time to be used for the data processing
- 6) In case clock time is selected insert the LAT LON values. If GPS time is selected coordinates will be automatically retrieved from FloX raw data.
- 7) Select if the possible spectral shift of the FULL spectrometer has to be automatically corrected.

Figure 1 FloX Processing GUI.



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8) Select if the data processing needs to account for spectrometer non linearity (NL) correction.

9) Select if the spectral convolution needs to be applied.

10) Specify the full width at half maximum (FWHM) of the deconvolved spectrum and the related spectral sampling interval (SSI). In nanometer.

11) Select if the spline smoothing needs to be applied on reflectance factor

12) Specify the related degree of freedom.

13) Select the output data to be saved.

14) Launch the processing with the start processing button.

GUI Input

Input of the GUI are:

1) Calibration file

Calibration files are provided from JB at the moment of the FLOX delivery and contain the information related to spectral and radiometric factors to convert raw data into physical units ($W\ m^{-2}\ sr^{-1}\ nm^{-1}\ ms^{-1}$). WARNING: If calibration file is provided accounting for non linearity the processing must be launched applying the non linearity correction.

2) Indices file

Indices file is a .txt file format containing the vegetation indices information. Each index is defined by 5 fields: Index name (Index, e.g. NDVI), bands center (wl, "800;670"), band width in nanometers (fwhm, e.g. "10;10"), index formulation (expression, e.g. $(a-b)/(a+b)$), convolution in the selected spectral range (convolution, e.g. mean or gaussian), Spectrum where to calculate the indices (e.g. R for reflectance, L for reflected radiance). The indices file is open

to modification by the users, who is free to add as many reflectance based indices as desired, appending them as new lines in the file.

3) FloX data path

Path where the FloX data are stored. WARNING: path refers to the main folder where the subfolders named as the day of the measurements are contained, as from the SD card data structure. Flox files smaller than 100 MB are excluded from the processing.

4) SIF retrieval Method

Two options are available: improved Fraunhofer Line Discriminator (iFLD) and Spectral Fitting Method (SFM). iFLD option allows a quick processing which is recommended first.

5) Time to use

Two options are available: FloX internal clock and FloX GPS module. For outdoor installation GPS time is recommended. For indoor measurements GPS time could be not available and clock time is preferred.

6) Coordinates

In case GPS time is selected this information is discarded. If clock time is selected the users can manually insert the coordinates. Warning: after coordinates insertion press enter.

7) Select data to save

Three options are available: Radiance, Reflectance and Parameter. In case Radiance or reflectance are selected radiances or reflectance files are generated and saved during the data processing. If Parameter selected a summary file is produced during the processing (see Output for details).

8) FULL shift correction

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A correction based on the position of atmospheric absorption feature can be applied to compensate for this changes.

9) NL correction

Non linearity correction can be applied by selecting the relative flag. **WARNING:** This selection should be aligned with the calibration file provided by JB. In case of doubt contact JB directly.

10) CONVOLUTION/RESAMPLING

Specify if the user wants to deconvolve and resample the spectrum of Incoming and Reflected radiance and Reflectance of the FULL range spectrometer. In case the user is asked to define the FWHM and SSI of the deconvolution/resampling.

11) REFLECTANCE SPLINE SMOOTHING

Specify if the user wants to apply a spline smoothing to the reflectance factor from the FULL range spectroemeter. In case the

user is asked to specify the degree of freedom for the spline function.

GUI Output

Output files are saved in the main paths defined by the user. If radiance and reflectance output are selected to be saved, related files are stored in the same folder of the raw data. Output are saved separately for each spectrometer (FLUO and FULL suffix are used respectively) and for each channel: Incoming or reflected radiance.

The summary parameter file is saved in the main root aside a report of the data processing routine containing information on the number of measurements and days processed, the calibration files used and the processing configuration settings.

The parameter file contains a list of files sorted by date and structured as reported in the following table.

Notes

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Field name	Description
doy.dayfract	Day of the year and day fraction
datetime [UTC]	Date time, format UTC
SZA	Solar Zenith Angle
Lat	Latitude
Lon	Longitude
temp1 [C]	Temperature of QEPro CCD
temp2 [C]	Temperature of QEPro housing
temp3 [C]	Temperature of FloX mainboard
temp4 [C]	Temperature of FloX spectrometer compartment
h1 [%]	Humidity at the main controller
h2 [%]	Humidity inside the spectrometer compartment
Incoming at 750nm [W m ⁻² nm ⁻¹ sr ⁻¹]	Incoming radiance at wavelength 750 nm
Reflected 750 [W m ⁻² nm ⁻¹ sr ⁻¹]	Reflected radiance at wavelength 760 nm
Reflected 760 [W m ⁻² nm ⁻¹ sr ⁻¹]	Reflected radiance at wavelength 760 nm
Reflected 687 [W m ⁻² nm ⁻¹ sr ⁻¹]	Reflected radiance at wavelength 687 nm
Reflectance 750 [-]	Reflectance at wavelength 750 nm
Reflectance 760 [-]	Reflectance at wavelength 760 nm
E_stability [%]	Percentage difference between WR1 and WR2. Fluo range
sat value L [boolean]	Saturation value of downward channel. Fluo range
sat value E [boolean]	Saturation value of upward channel 1. Fluo range
sat value E2 [boolean]	Saturation value of upward channel 2. Fluo range
Dynamic range E [%]	Dynamic range covered of upward channel. Fluo range
Dynamic range L [%]	Dynamic range covered of downward channel. Fluo range
SIF_A_ifld [mW m ⁻² nm ⁻¹ sr ⁻¹]	SIF at O2A band (760 nm). iFLD method
SIF_B_ifld [mW m ⁻² nm ⁻¹ sr ⁻¹]	SIF at O2B band (687 nm). iFLD method
Incoming at 750nm Full [W m ⁻² nm ⁻¹ sr ⁻¹]	Incoming radiance at wavelength 750 nm. Full range
Reflected 750nm full [W m ⁻² nm ⁻¹ sr ⁻¹]	Reflected radiance at wavelength 750 nm. Full range
PAR inc [W m ⁻²]	Photosynthetically Active Radiation
PAR ref [W m ⁻²]	Reflected Photosynthetically Active Radiation
APAR [umol m ⁻² s ⁻¹]	Absorbed Photosynthetically Active Radiation
E_stability full [%]	Percentage difference between WR1 and WR2. Full range
sat value L full [boolean]	Saturation value of downward channel. Full range
sat value E full [boolean]	Saturation value of upward channel 1. Full range
sat value E2 full [boolean]	Saturation value of upward channel 2. Full range
Dynamic range E full [%]	Dynamic range covered of upward channel. Full range
Dynamic range L full [%]	Dynamic range covered of downward channel. Full range
SSHIFT [nm]	Spectral shift of Full range spectrometer
Vegetation Indices	Various VIs defined in indices.txt file (Full range based)

Appendix

DUST & BIRD PROTECTION

Last Update: 2019-06-19 FloX Firmware: 2.08

Overview

The upward looking cosine receptors of FloX and RoX instruments are exposed directly to environmental hazards. To increase longevity, the Dust & Bird Protection system is used to keep the surface of the cosine receptor clean and to prevent bird damage. The active airstream also provides some protection against settling of insects, rain and snow on the optics. Further the Dust & Bird Protection is designed for robust attachment to tower structures and accurate levelling. The device, including the fan is completely weatherproof.

Setup Considerations

The Dust & Bird Protection requires a careful setup to achieve reliable measurements (ref. PERMANENT INSTALLATION & MOBILE USE). The system should be positioned at the highest possible mounting point of the tower with nothing around, which obstructs the hemispherical field of view. The length of the optical fibres and the length of the 12 V power supply cable needs to be considered. Before setup, make sure there is a way to properly level the Dust & Bird protection using the bubble level on the device itself.

How To

To mount the cosine receptors into the Dust & Bird protection, first remove the fan by unscrewing the screws in the 4 corners. Lead the fibers through the vertical openings in the back and fix the cosine receptors in the upper holder using the small screws. Make sure both cosine receptors are rising 1-2 mm above the holder. Eventually use tape or silicon to seal the vertical openings in the back. Again mount the fan, with the blowing direction upwards.

To attach the Dust & Bird Protection to a mast, use U-Double-Screws or any other given option. A variety of standard spacings are supported by the mounting holes of the device. However it's fine to drill additional holes in the baseplate to support other ways of mounting.

After mounting to the mast, perform an accurate levelling of the device in order to achieve the optimum cosine response. Use the bubble level on top.

See Figure 1 for details on dimensions and positions.

Electrical Connections

The Dust & Bird Protection fan runs on 12 V and requires 1 Watt peak power. Polarity is given on the cables (Tests have shown the fans are reverse polarity protected). Make sure the fan is always powered and running since only a consistent airstream will prevent settling of dust on the optics. In an off-grid power scenario it is recommended to wire the fan directly to the buffer battery, thus bypassing any charge controller which could eventually switch the fan off due to low battery.

Warning Notes

When climbing towers and ladders ensure you've a safe stand and proper safety gear. Do not work alone.

Do not bend the optical fibres below a radius of 8 cm. A lower radius will alter the calibration and a narrow bending can break the fibre.

DUST & BIRD PROTECTION

Last Update: 2019-06-19 FloX Firmware: 2.08

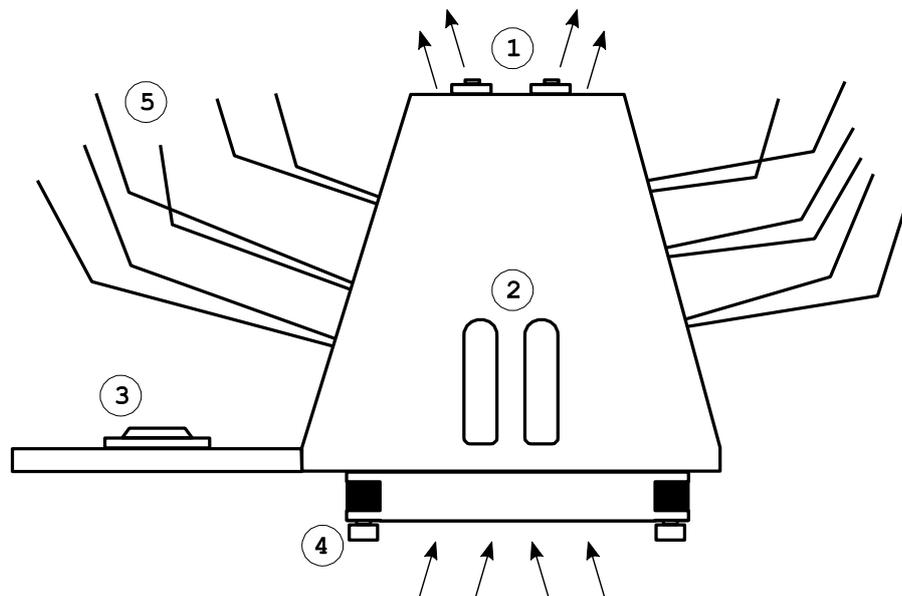
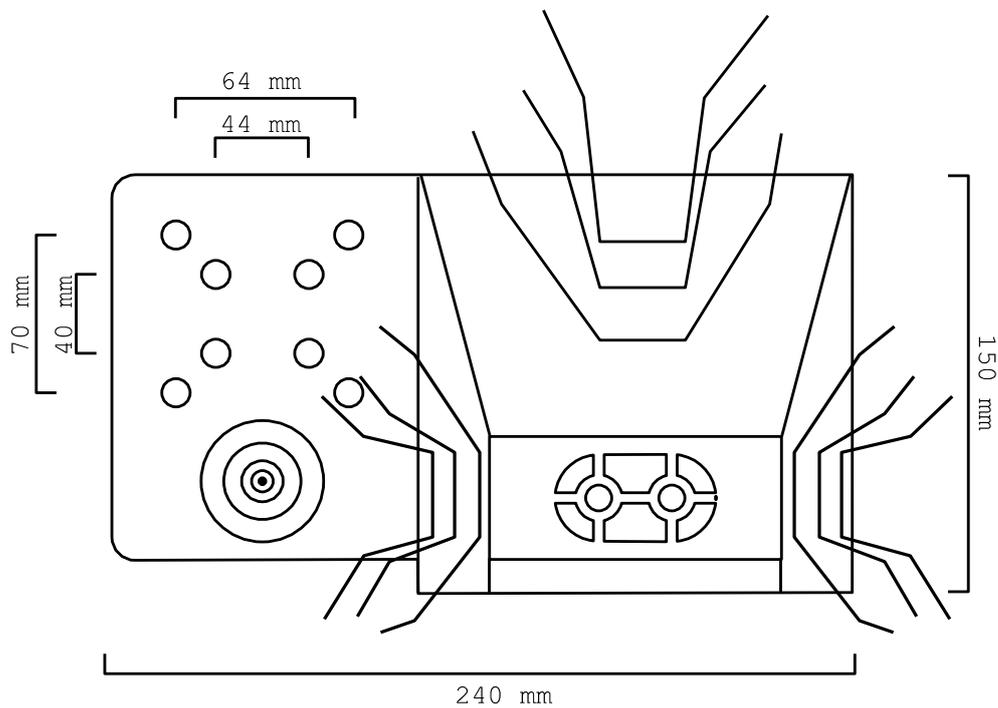


Figure 1 Top: Top view of the Dust & Bird protection, including dimensions (measured from hole center for spacings)

Figure 1 Bottom: Back view of the device. Arrows are indicating the direction of the airstream. 1) Cosine Receptors 2) Fiber Intakes 3) Levelling Bubble 4) Fan with screws 5) Spikes to make birds feels uncomfortable

LITERATURE LIST

Last Update: 2020-11-06

Literature List

- Diurnal dynamics of non-photochemical quenching in Arabidopsis npq mutants assessed by solar-induced fluorescence and reflectance measurements in the field. *New Phytologist*. 2020.K. Acebron,S. Matsubara,C. Jedmowski,D. Emin, O. Muller and U. Rascher
- CloudRoots: integration of advanced instrumental techniques and process modelling of sub-hourly and sub-kilometre land-atmosphere interactions, *Biogeosciences*. 2020 Vilà-Guerau de Arellano, J., Ney, P., Hartogensis, O., de Boer, H., van Diepen, K., Emin, D., de Groot, G., Klosterhalfen, A., Langensiepen, M., Matveeva, M., Miranda-García, G., Moene, A. F., Rascher, U., Röckmann, T., Adnew, G., Brüggemann, N., Rothfuss, Y., and Graf, A.
- Fluorescence Correction Vegetation Index (FCVI): A physically based reflectance index to separate physiological and non-physiological information in far-red sun-induced chlorophyll fluorescence. *Remote Sensing of Environment*, 2020. Peiqi Yang, Christiaan van der Tol, Petya K.E.Campbell, Elizabeth M.Middleton
- Reduction of structural impacts and distinction of photosynthetic pathways in a global estimation of GPP from space-borne solar-induced chlorophyll fluorescence. *Remote Sensing of Environment*. 2020. Zhaoying Zhanga, Yongguang Zhanga, Albert Porcar-Castell, Joanna Joiner, Luis Guanter, Xi Yang, Mirco Migliavacca, Weimin Ju, Zhigang Sun, Shiping Chen, David Martini, Qian Zhang, Zhaohui Li, James Cleverly, Hezhou Wang, Yves Goulas
- Unmanned Aerial Systems (UAS)-Based Methods for Solar Induced Chlorophyll Fluorescence (SIF) Retrieval with Non-Imaging Spectrometers: State of the Art. *Remote Sensing* 2020. Juan Quirós Vargas,Juliane Bendig,Alasdair Mac Arthur,Andreas Burkart,Tommaso Julitta,Kadmiel Maseyk,Rick Thomas 7,Bastian Siegmann,Micol Rossini, Marco Celesti, Dirk Schüttemeyer, Thorsten Kraska, Onno Muller and Uwe Rascher
- Effects of varying solar-view geometry and canopy structure on solar-induced chlorophyll fluorescence and PRI. K. Biriukova, M. Celesti, A. Evdokimova, J. Pacheco-Labrador, T. Julitta, M. Migliavacca, C. Giardino, F. Miglietta, R. Colombo, C. Panigada, M. Rossini
- Remote sensing of solar-induced chlorophyll fluorescence (SIF) in vegetation: 50 years of progress. G. H.Mohammed, R. Colombo, E. M.Middleton, U. Rascher, C. van der Tol, L. Nedbald, Y. Goulas, O. Pérez-Priego, A. Damm, M. Meroni, J. Joiner, S. Cogliati, W. Verhoef, Z. Malenovskýk, J. Gastellu-Etchegorry, J. R. Miller, L. Guanter, J. Moreno ... P.J.Zarco-Tejada.
- Diurnal and Seasonal Variations in Chlorophyll Fluorescence Associated with Photosynthesis at Leaf and Canopy Scales. *Remote Sensing*. 2019 Petya K. E. Campbell, Karl F. Huemmrich, Elizabeth M. Middleton, Lauren A. Ward, Tommaso Julitta, Craig S. T. Daughtry, Andreas Burkart, Andrew L. Russ and William P. Kustas

LITERATURE LIST

Last Update: 2020-11-06

- Sun-induced fluorescence and gross primary productivity during a heat wave. Scientific Reports. volume 8, Article number: 14169 (2018) G. Wohlfahrt, K. Gerdel, M. Migliavacca, E. Rotenberg, F. Tatarinov, J. Müller, A. Hammerle, T. Julitta, F. M. Spielmann & D. Yakir
- Proximal VIS-NIR spectrometry to retrieve substance concentrations in surface waters using partial least squares modelling. Water Supply ws2018177. A. Wagner S. Hilgert T. Kattenborn S. Fuchs
- Recent development and results of very high-resolution spectroscopy for the measurement of time series of sun induced fluorescence. 10th EARSeL SIG Imaging Spectroscopy Workshop | 19-21April 2017, Zurich, Switzerland. Burkart A. Julitta T. Schickling A. Pilar C. Wieneke S. Migliavacca M. Colombo R. Rascher U.
- Comparing the diurnal and seasonal dynamics in chlorophyll fluorescence and xanthophyll cycle, associated with photosynthetic function for two vastly different canopies. Campbell P. Middleton E. Julitta T. Huemmrich K., Garish C. Burkart A.
- Sun-Induced Chlorophyll Fluorescence I: Instrumental Considerations for Proximal Spectroradiometers. Javier Pacheco-Labrador, Andreas Hueni, Laura Mihai, Karolina Sakowska, Tommaso Julitta, Joel Kuusk, Dan Sporea, Luis Alonso, Andreas Burkart, M. Pilar Cendrero-Mateo, Helge Aasen, Yves Goulas , Alasdair Mac Arthur
- Sun-Induced Chlorophyll Fluorescence II: Review of Passive Measurement Setups, Protocols, and Their Application at the Leaf to Canopy Level. H. Aasen, S. Van Wittenberghe, N. Sabater Medina, A. Damm, Y. Goulas, S. Wieneke, A. Hueni, Z. Malenovský, L. Alonso, J. Pacheco-Labrador, M. Pilar Cendrero-Mateo, E. Tomelleri, A. Burkart, S. Cogliati, U. Rascher, A. Mac Arthur
- Sun-Induced Chlorophyll Fluorescence III: Benchmarking Retrieval Methods and Sensor Characteristics for Proximal Sensing. M. Pilar Cendrero-Mateo, Sebastian Wieneke, Alexander Damm, Luis Alonso, Francisco Pinto, Jose Moreno, Luis Guanter, Marco Celesti, Micol Rossini, Neus Sabater, Sergio Cogliati, Tommaso Julitta, Uwe Rascher, Yves Goulas, Helge Aasen, Javier Pacheco-Labrador, Alasdair Mac Arthur

Disclaimer:

This literature list is an excerpt of a growing number of publications and is intended as a starting point for the scientific work on measurements of sun-induced fluorescence using hyperspectral instruments.