FACE-IT NY-ALESUND MESOCOSM EXPERIMENT

Experimental system documentation

pierre urrutti

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1. Experimental system

Twelve 1 m^3 mesocosms will be installed on the Kings Bay outdoor platform (Fig. 1). Dimensions of each mesocosm are provided in Fig. 2.

Fig. 1. Outdoor platform of the Kings Bay marine lab.

All mesocosms are closed with a circular cover made out of fiberglass (around) and acrylic. Light filters (see thereafter) will be added on top of the acrylic.

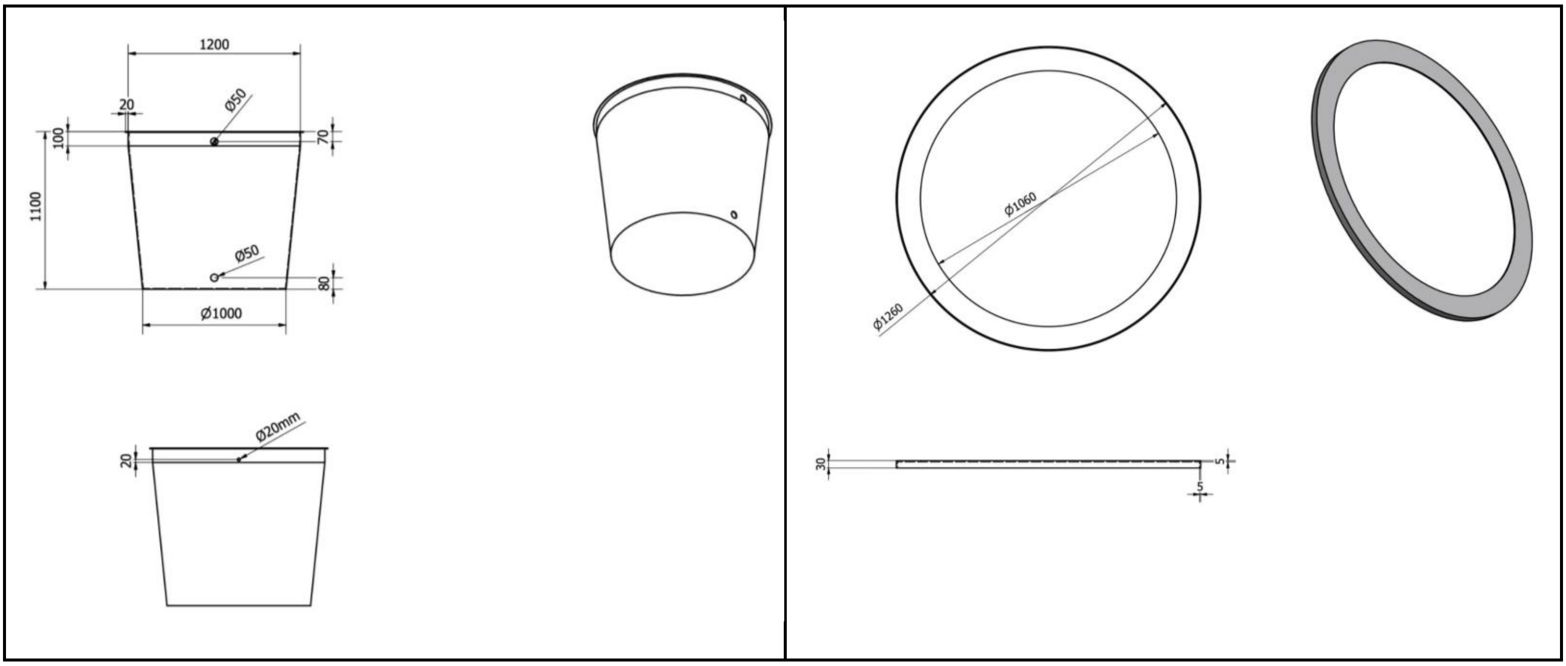


Fig. 2. Scheme and dimensions of mesocosms in mm.

2. Treatment design

The experiment consists of 12 x 1m3 mesocosms, representing 3 different scenarios along with 1 control. We therefore have 3 mesocosms per condition. Each mesocosm will receive 0.5m3/h of seawater in open cycle.

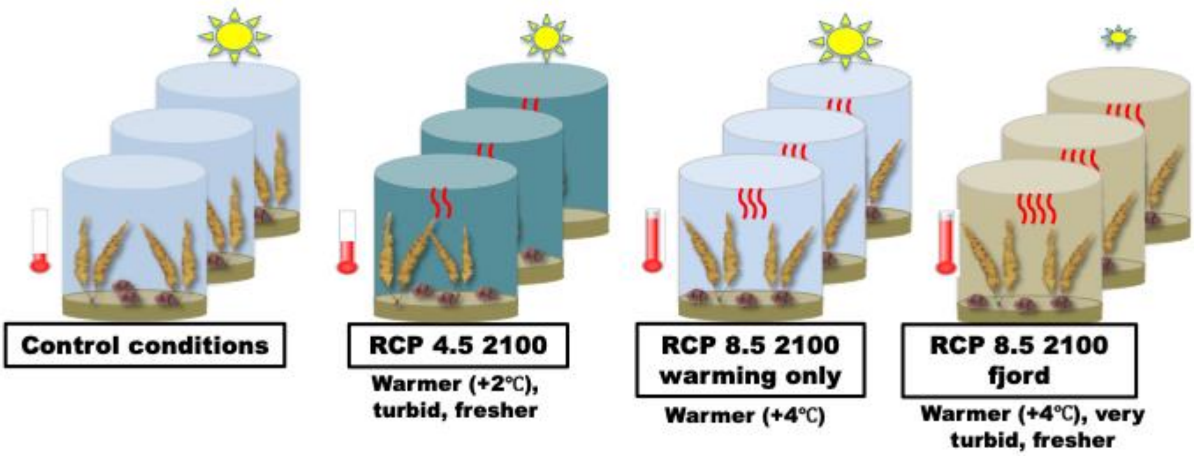


Fig. 4. Different scenarios considered in addition to unaltered conditions (to be modified)

The control condition is meant to represent the actual in situ condition in Kongsfjorden at 11m deep. The setpoints (temperature and salinity) for this control condition is given by data logged by a ferry box located on site (using data provided by https://dashboard.awi.de/).

Since the seawater is pumped 300 meters away, and runs in pipes through a heated building, it may be necessary to lower the incoming seawater temperature to fit the in-situ temperature. Therefore, the 3 control mesocosms will receive ambient seawater as well as chilled seawater.

The other 9 mesocosms will receive ambient sea water and hot sea water to fit their condition with the different scenarios.

6 of these mesocosms will also receive fresh water in order to lower the salinity.

According to the scenario, the computer will calculate the salinity difference between control and the scenario, using the linear regressions showed in figure 6. This delta is then used to set the salinity setpoint for every mesocosm of the corresponding scenario.

Table 1: Temperature and salinity projections for Ny-Alesund (78.5°N, 11.5°E) following different CO_2 emissions scenarios. The difference between the periods 1995-2014 and 2080-2099 is shown (data courtesy: Jens Terhaar, jens.terhaar@climate.unibe.ch)

	Differences between 1995-2014 and 2080-2099 for open waters	
Projection scenario	**Δ**T (°C)	**Δ**S
SSP126	2.5	0
SSP245	3.3	0
SSP370	4.4	-0.1
SSP585	5.3	-0.2

Salinity

The offsets for salinity inside the fjord cannot be taken from the outputs of Earth System Models that work on a regional scale (1° x 1° grid). Based on TS data measured in the ferry box in summer (week 22 to 35), we could establish a relationship between T and S (blue points and curve in the figure below) and based on this relationship, extrapolate the salinity levels for the 4 projection scenarios.

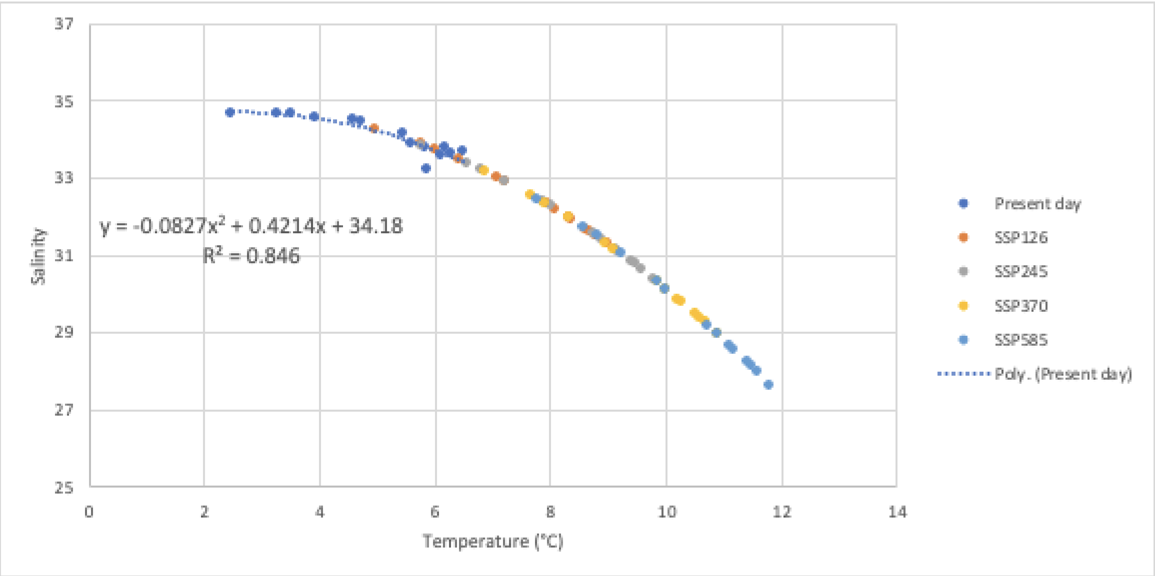


Fig. 5. Relationship between temperature and salinity in summer (data from the ferry box) in Ny-Alesund. This relationship has been extrapolated using temperature offsets projected for 2100 from the four SSP scenarios.

A dynamic regulation for salinity will be applied based on the measured *in situ* temperature levels during the experiment, following the linear relationships shown in the figure below.

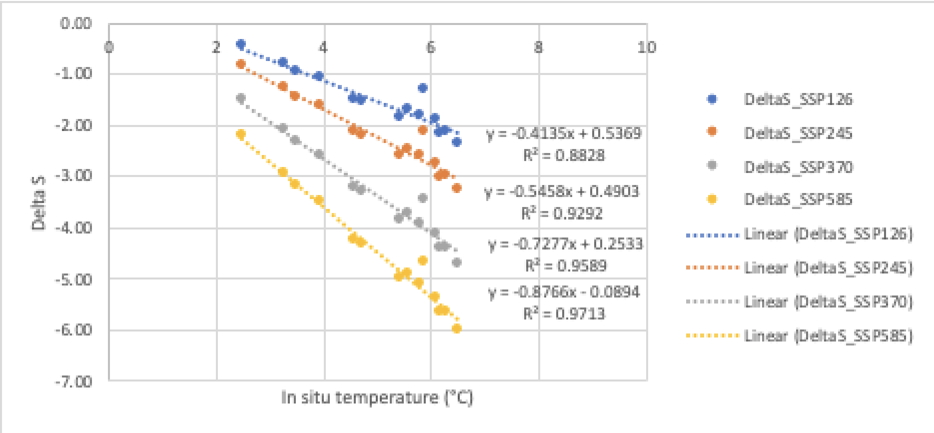
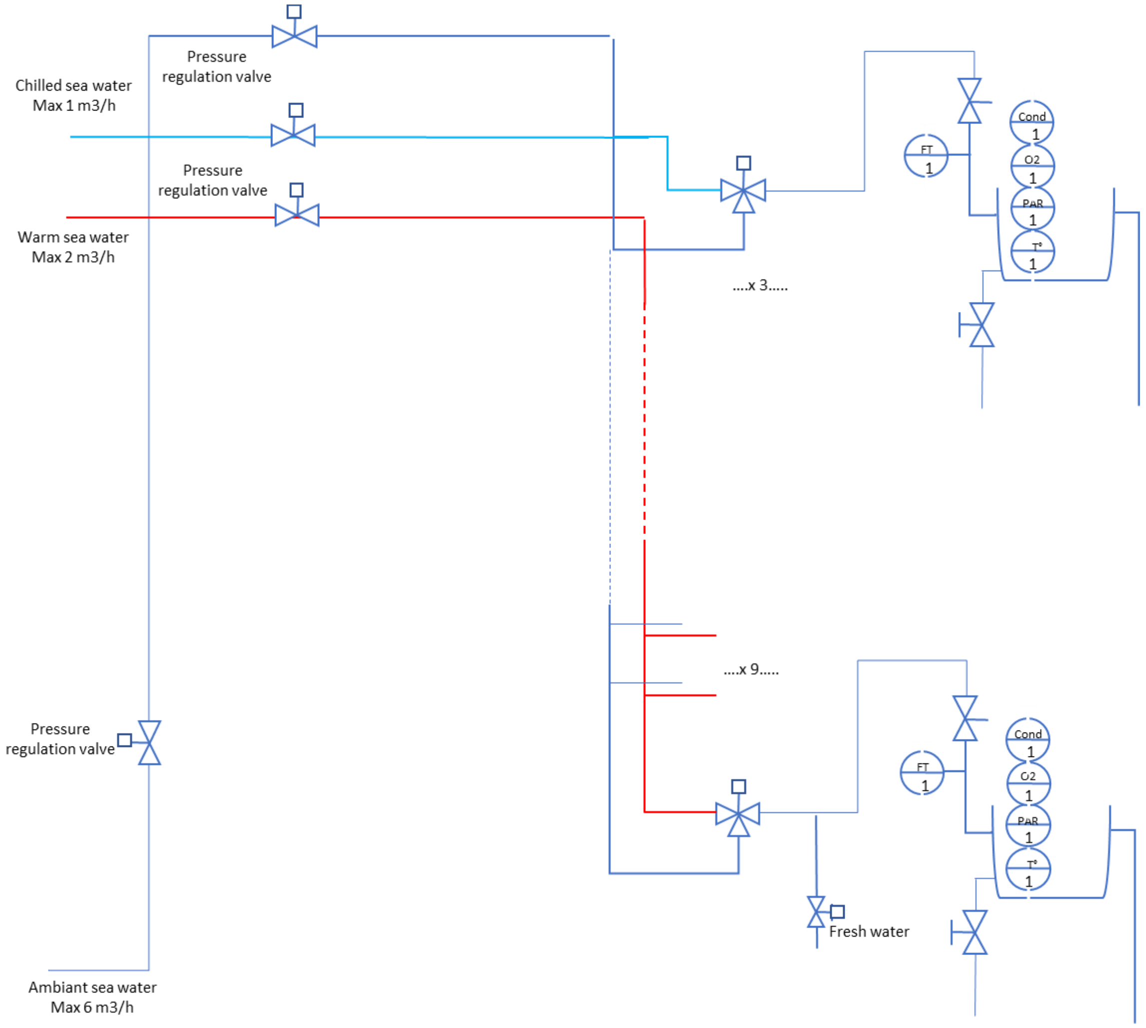


Fig. 6. Relationship between salinity offsets and measured in situ temperature.

<u>Light conditions</u>

Light filters have been purchased to reproduce light intensity and spectrum as measured in the Fjord at 8 m (data courtesy of Kai Bischof).

3. Piping



The system consists of 12 mesocosms, each fed with 0.5m3/h of seawater running in open cycle.

The system will be fed with seawater coming from 3 different sources:

- Ambient seawater (max 6m3/h)
- Chilled seawater (max 1m3/h) to lower the control condition temperature if needed
- Warm seawater (max 2 m3/h) to raise the water temperature in the different scenarios.

a. Pressure regulation

Each seawater input has its own pressure regulation system, in order to maintain equivalent pressure levels, making it easier to adjust the flowrates in the mesocosms. This system consists of an analog pressure sensor (Siemens 7MF1567-3BE00-1AA1) and a two-way analog valve (BELIMO R2025-10-S2 with LR24A-SR motor). We set a pressure setpoint for all 3 sensors and the system adjusts the valve opening in order to regulate the pressure to the setpoint.

b. Temperature regulation

Each mesocosm has a three-way analog mixing valve (BELIMO R3015-10-S2 with LR24A-SR motor) in order to adjust the temperature. The system sets a temperature setpoint (depending on the scenario and on the in-situ measurements) and it adjusts the valve opening (using a PID regulator) to fit the measure to the setpoint.

c. Flowrate regulation

Flowrate for each mesocosm is manually regulated. The inlet piping for each mesocosm has a manual flowrate regulation valve, and an analog flowrate sensor (IFM SV3150). During the commissioning of the experiment, we need to adjusts all the valve openings in order to obtain a 0.5 m3/h flowrate in every mesocosm.

d. Salinity regulation

6 mesocosms (scenarios 1 and 3) have a two-way analog valve (BELIMO R2015-10-S2 with LR24A-SR motor) in order to input fresh water. The system sets a salinity setpoint (depending on the scenario and on the in-situ measurements) and it adjusts the valve opening (using a PID regulator) to fit the measure to the setpoint.

e. Sensors

Each mesocosm has 3 different sensors:

- Salinity sensor (Aqualabo SN-PC4E): Measures the conductivity (and converts to salinity) and the temperature
- Oxygen sensor (Aqualabo SN-Podoc): Measures the 02 (in % and converts to mg/L) and the temperature
- PAR sensor (ODYSSEY PAR Logger): Measures photosynthetic light levels (not connected to the automation PLCs).

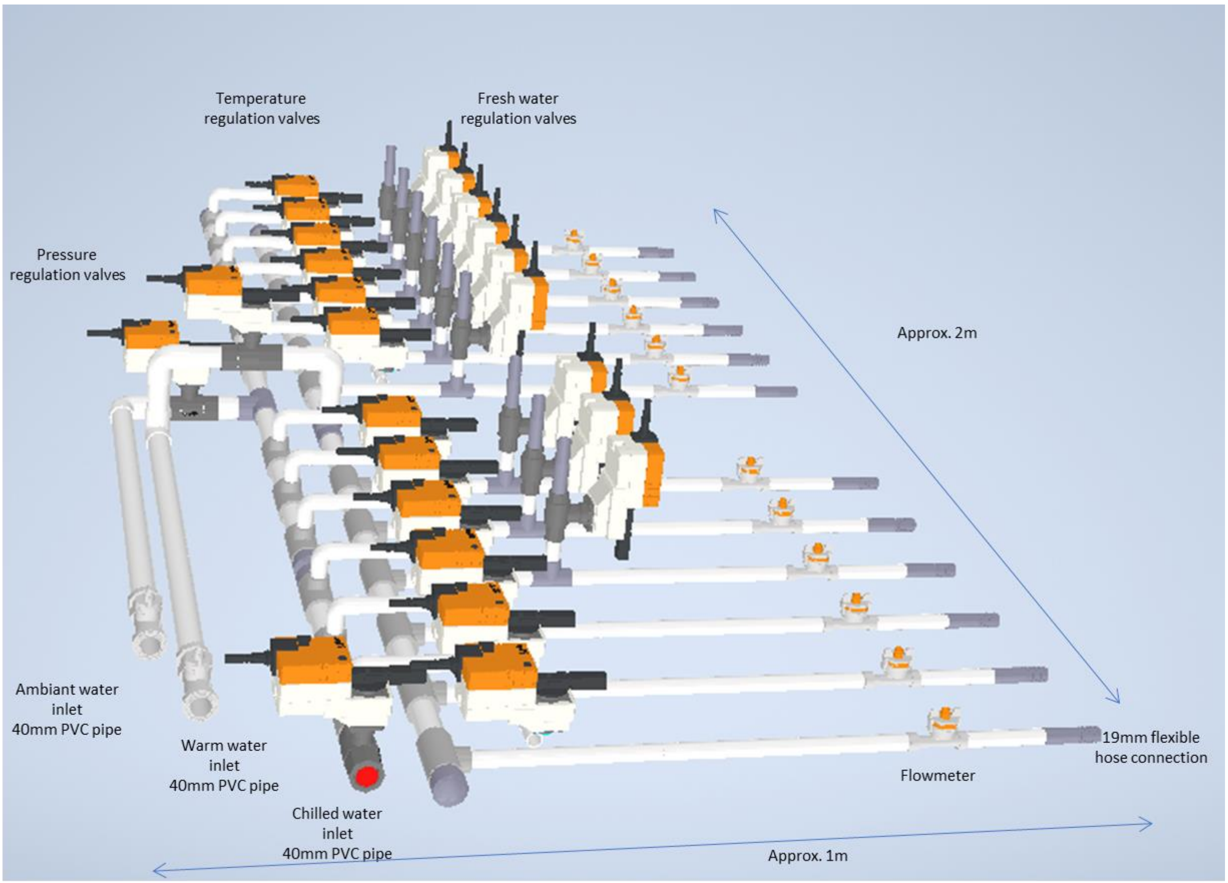
f. Piping

General Inlet pipings are made of 40mm PE hoses.

The regulation skid is made of 20mm to 40mm PVC pipes.

Mesocosm inlet pipes are 19mm flexible hoses.

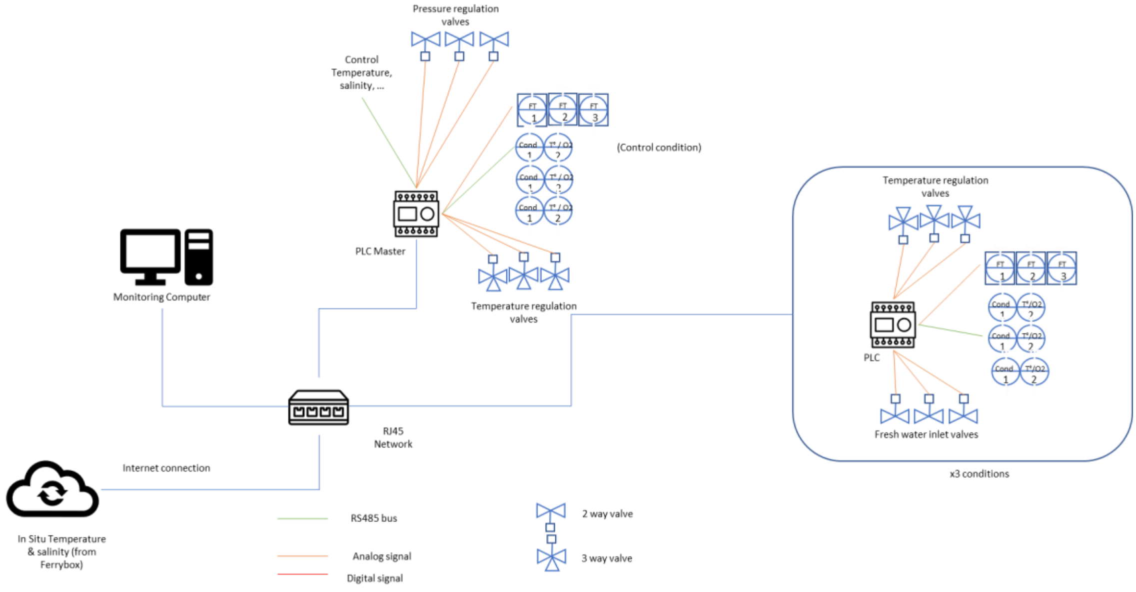
Mesocosm outlet pipes are 50mm PVC pipes


Temperature
regulation valves
Fresh water
regulation valves
Pressure
regulation valves
Approx. 2m
Ambiant water
inlet
40mm PVC pipe
Warm water
inlet
40mm PVC pipe
Chilled water
inlet
40mm PVC pipe
19mm flexible
hose connection
Flowmeter
Approx. 1m

4. Automation

a. Overview

Automation
Hardware architecture



The automation of the experiment is made using 4 Industrial Arduino-based PLCs (Industrial shields Mduino-42+).

Each PLC is responsible for the data logging and regulation of a specific scenario (hence 3 mesocosms each).

One PLC, Master, is also responsible for the communication between PLCs and the Monitoring computer.

The monitoring computer runs a Windows application developed in C#, responsible for:

- Reading data received from the PLCs
- Reading in-situ data received from the internet
- Displaying live data
- Logging data and sending to a FTP server
- Sending settings and commands to the PLCs

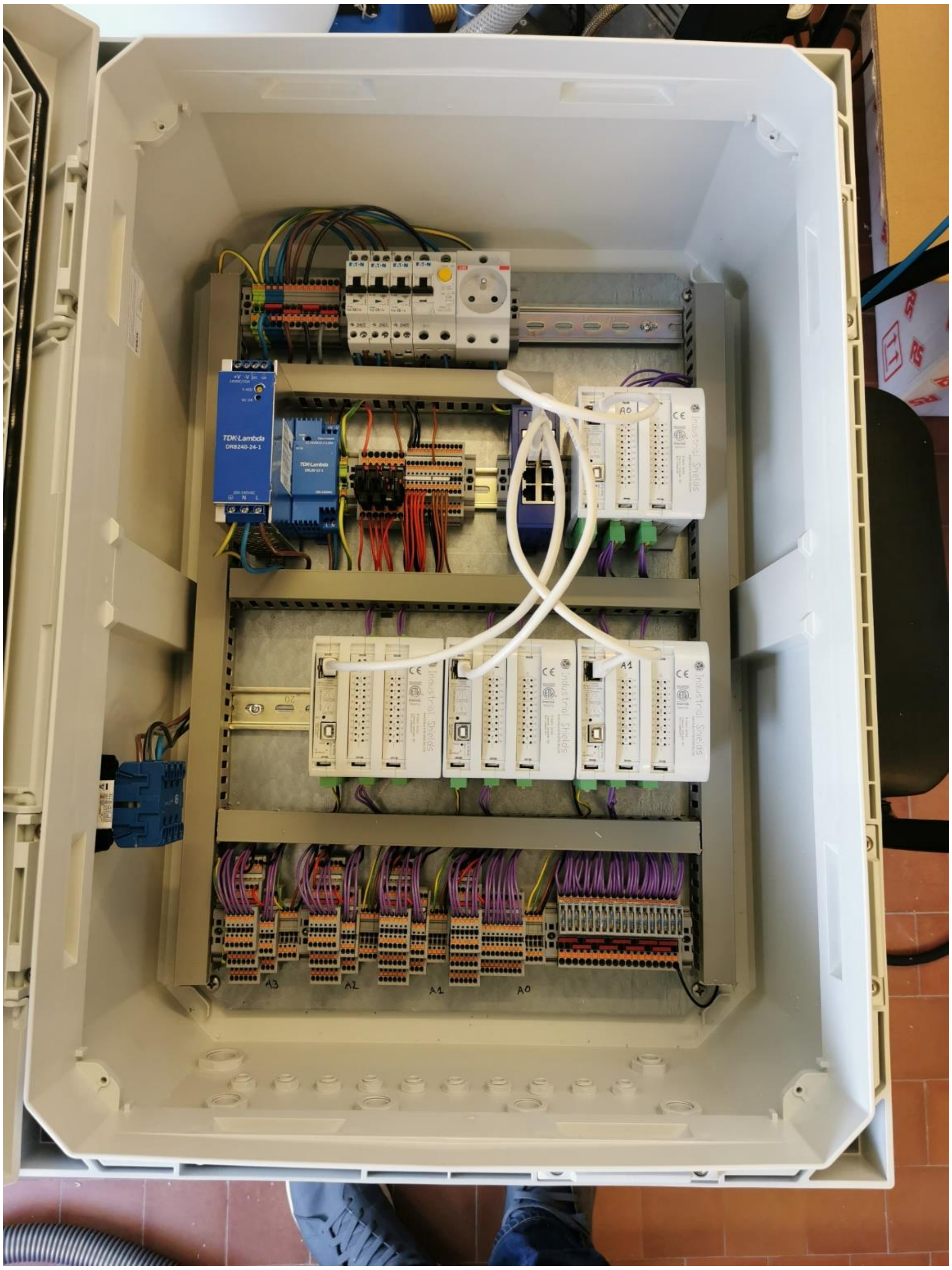
Communication between the PLCs and the PC is made using http WebSocket protocol on RJ45 ethernet cables.

Communication between PLCs and flowrate sensors is made analog 4-20mA signal.

Communication between PLCs and sensors is made using half duplex RS485 (2 wires) protocol.

Communication between PLCs and regulation valves is made using analog 0-10V signal.

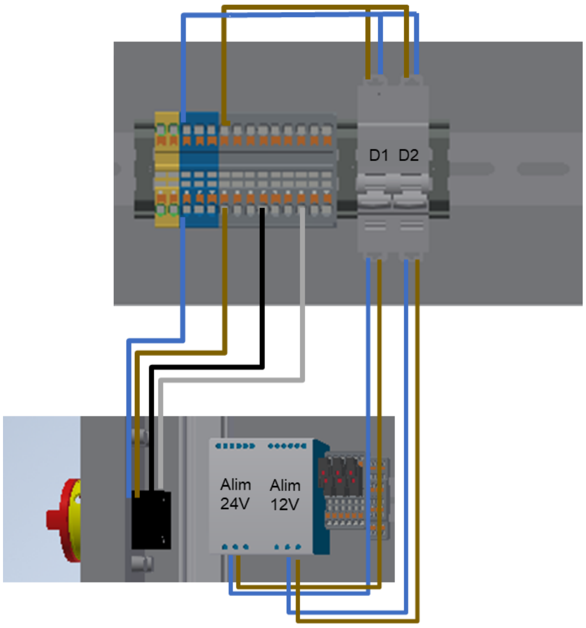
b. Electrical cabinet



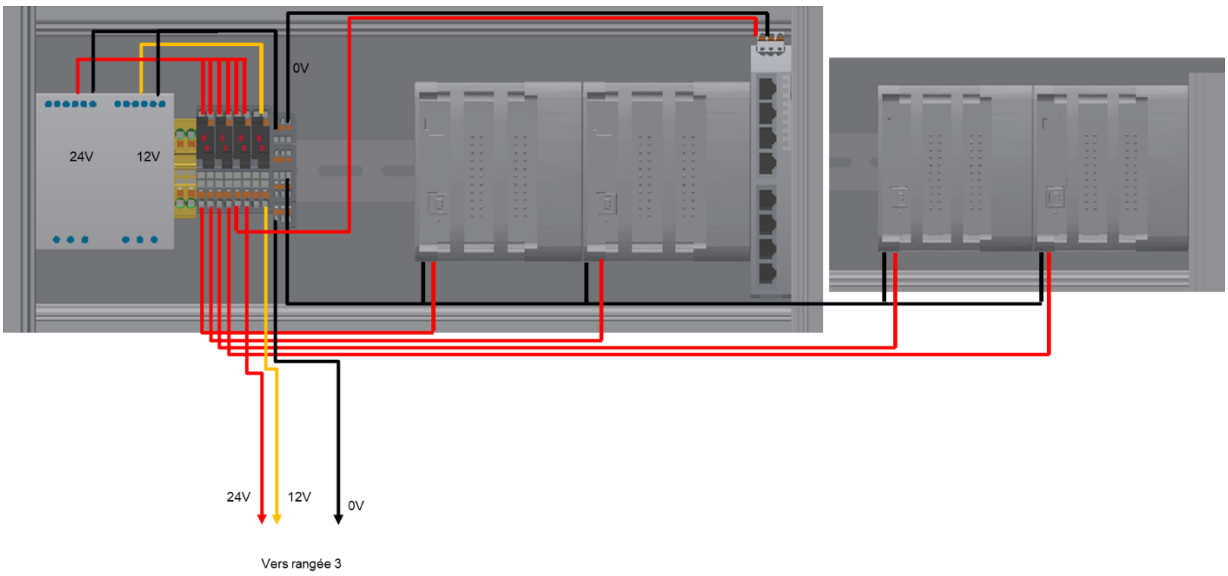
The electrical cabinet is an IP68 Fibox enclosure with a 400 V (3P+N+E) 32A security switch.

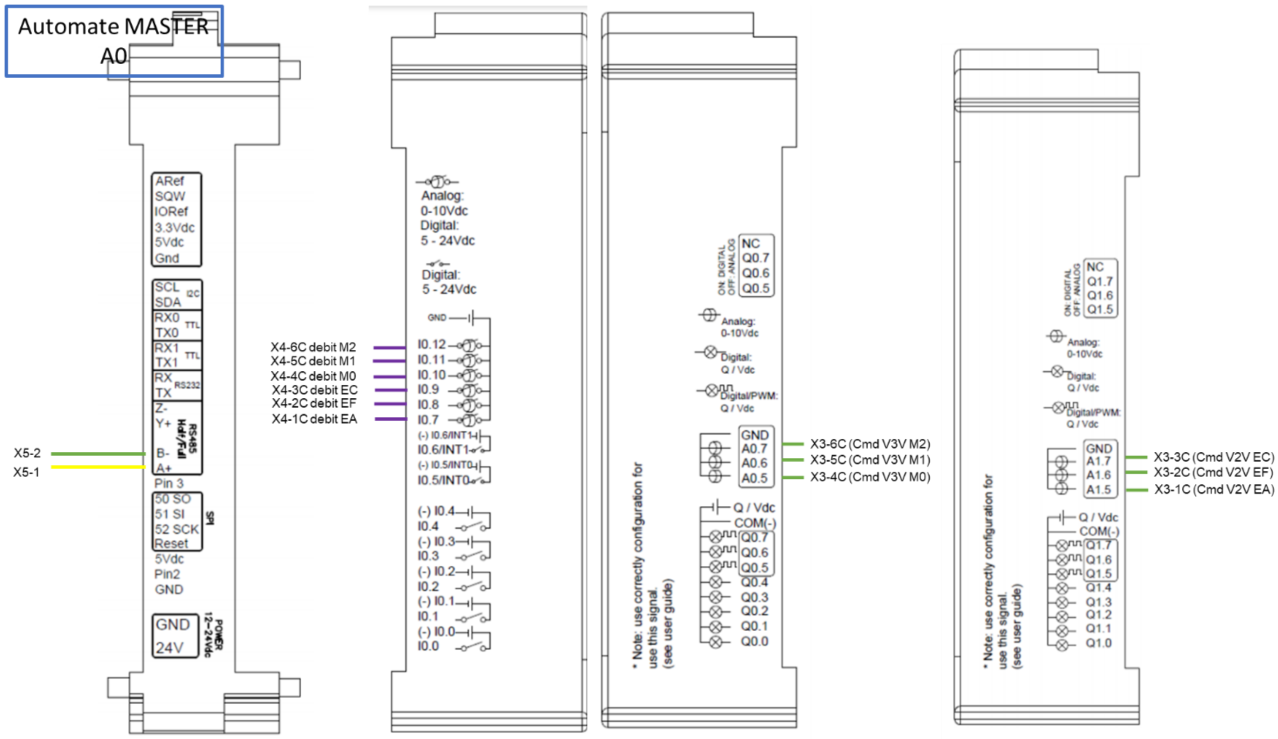
All the automation elements use Low tension (12Vdc or 24Vdc) through circuit breakers and fuses. An additional protected 220V socket is available.

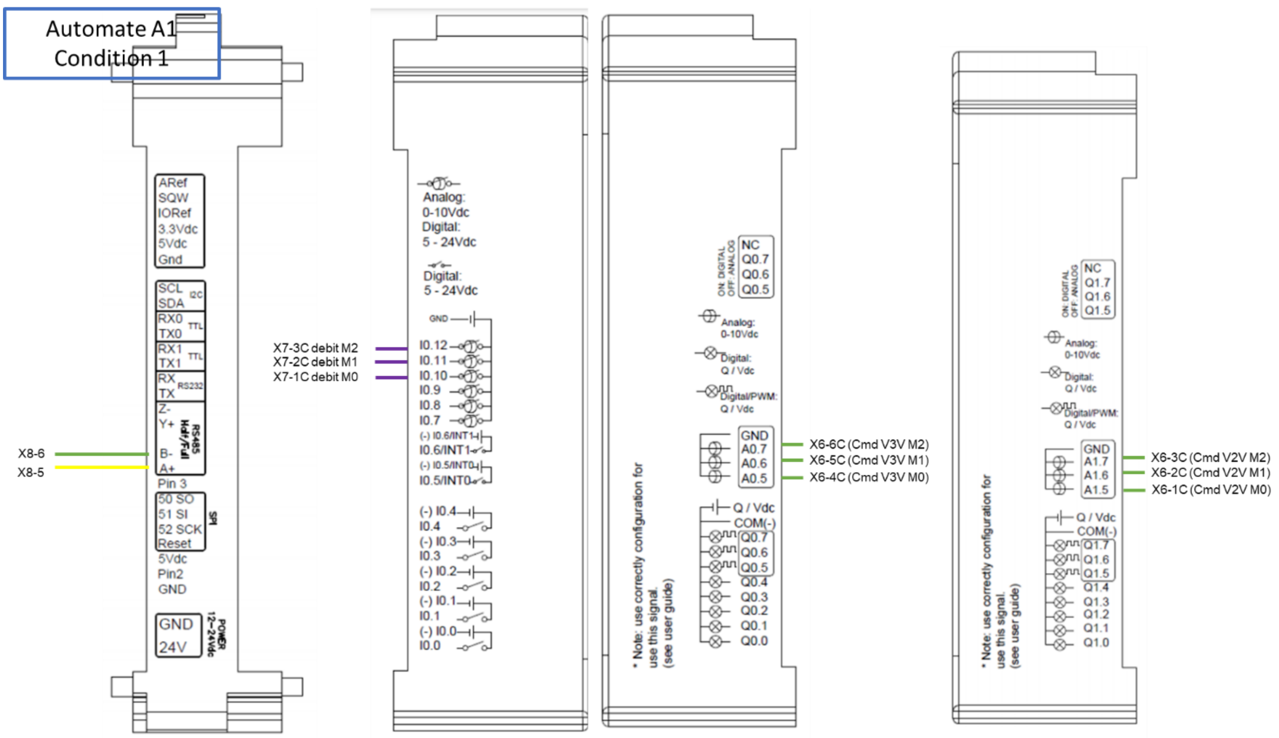
c. Electrical schematics

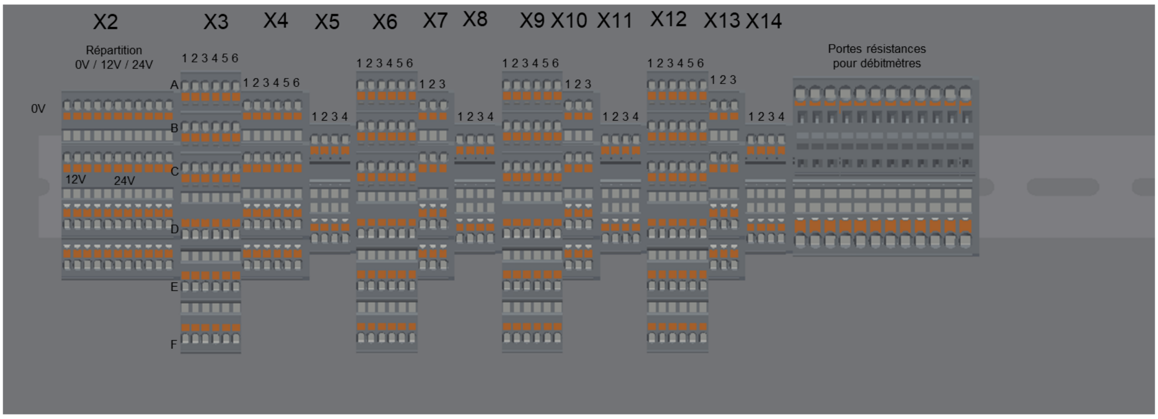


D1: Alim 24Vdc
D2: Alim 12Vdc




Automate MASTER A0
X5-2
X5-1
X4-6C debit M2
X4-5C debit M1
X4-4C debit M0
X4-3C debit EC
X4-2C debit EF
X4-1C debit EA
X3-6C (Cmd V3V M2)
X3-5C (Cmd V3V M1)
X3-4C (Cmd V3V M0)
X3-3C (Cmd V2V EC)
X3-2C (Cmd V2V EF)
X3-1C (Cmd V2V EA)
ARef
SQW
IORef
3.3Vdc
5Vdc
Gnd
SCL
SDA
RX0
TX0
RX1
TX1
RX
TX
Z-
Y+
B-
A+
Pin 3
50 SO
51 SI
52 SCK
Reset
5Vdc
Pin2
GND
GND
24V
Analog:
0-10Vdc
Digital:
5 - 24Vdc
Digital:
5 - 24Vdc
NC
Q0.7
Q0.6
Q0.5
GND
A0.7
A0.6
A0.5
Q / Vdc
COM(-)
Q0.4
Q0.3
Q0.2
Q0.1
Q0.0
NC
Q1.7
Q1.6
Q1.5
GND
A1.7
A1.6
A1.5
Q1.4
Q1.3
Q1.2
Q1.1
Q1.0
* Note: use correctly configuration for use this signal. (see user guide)


Automate A1
Condition 1
X8-6
X8-5
X7-3C debit M2
X7-2C debit M1
X7-1C debit M0
X6-6C (Cmd V3V M2)
X6-5C (Cmd V3V M1)
X6-4C (Cmd V3V M0)
X6-3C (Cmd V2V M2)
X6-2C (Cmd V2V M1)
X6-1C (Cmd V2V M0)
ARef
SQW
IORef
3.3Vdc
5Vdc
Gnd
SCL
SDA
RX0
TX0
RX1
TX1
RX
TX
Z-
Y+
B-
A+
Pin 3
50 SO
51 SI
52 SCK
Reset
5Vdc
Pin2
GND
GND
24V
Analog:
0-10Vdc
Digital:
5 - 24Vdc
Digital:
5 - 24Vdc
NC
Q0.7
Q0.6
Q0.5
GND
A0.7
A0.6
A0.5
Q / Vdc
COM(-)
Q0.4
Q0.3
Q0.2
Q0.1
Q0.0
NC
Q1.7
Q1.6
Q1.5
GND
A1.7
A1.6
A1.5
Q1.4
Q1.3
Q1.2
Q1.1
Q1.0
* Note: use correctly configuration for use this signal. (see user guide)



Automate MASTER A0	X3						X4						X5			
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4
	V2V EA	V2V EF	V2V EC	V3V M0	V3V M1	V3V M2	Debitmetre EA	Debitmetre EF	Debitmetre EC	Debitmetre M0	Debitmetre M1	Debitmetre M2	RS485			
D	Cmd	Cmd	Cmd	Cmd	Cmd	Cmd	4-20mA	4-20mA	4-20mA	4-20mA	4-20mA	4-20mA	A	B	12Vdc	0Vdc
E	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc				
F	0V	0V	0V	0V	0V	0V										
Automate A1: Condition 1	X6						X7			X8						
	1	2	3	4	5	6	1	2	3	1	2	3	4			
	V2V M0	V2V M1	V2V M2	V3V M0	V3V M1	V3V M2	Debitmetre M0	Debitmetre M1	Debitmetre M2	RS485						
D	Cmd	Cmd	Cmd	Cmd	Cmd	Cmd	4-20mA	4-20mA	4-20mA	A	B	12Vdc	0Vdc			
E	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc							
F	0V	0V	0V	0V	0V	0V										
Automate A1: Condition 2	X9						X10			X11						
	1	2	3	4	5	6	1	2	3	1	2	3	4			
	V2V M0	V2V M1	V2V M2	V3V M0	V3V M1	V3V M2	Debitmetre M0	Debitmetre M1	Debitmetre M2	RS485						
D	Cmd	Cmd	Cmd	Cmd	Cmd	Cmd	4-20mA	4-20mA	4-20mA	A	B	12Vdc	0Vdc			
E	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc							
F	0V	0V	0V	0V	0V	0V										
Automate A1: Condition 3	X12						X13			X14						
	1	2	3	4	5	6	1	2	3	1	2	3	4			
	V2V M0	V2V M1	V2V M2	V3V M0	V3V M1	V3V M2	Debitmetre M0	Debitmetre M1	Debitmetre M2	RS485						
D	Cmd	Cmd	Cmd	Cmd	Cmd	Cmd	4-20mA	4-20mA	4-20mA	A	B	12Vdc	0Vdc			
E	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc	24Vdc							
F	0V	0V	0V	0V	0V	0V										

Carnet de câbles

Condition	Equipement	cable	longueur	boite de derivation	cable entree armoire	
Temoin	Vanne bullage CO2	**3x0,5**	5			
	sonde Fluo	**6x0,25b**	3			
	4x vannes d'exondation	**3x0,5**	12	1	**3x0,5**	6
	3x debitmetres	**2x0,25b**	3	1	**4x0,25b**	3
	9x capteurs de niveau	**2x0,25b**	9	3	**3x4x0,25b**	18
	Bus RS485	**4x0,25b**	(fourni)	1	**4x0,25b**	6
C1	Pompe peristaltique	**4x0,25b**	3			
	V3V temperature	**4x0,5**	3			
	3 x debitmetre	**2x0,25b**	3	1	**4x0,25b**	3
	9x capteurs de niveau	**2x0,25b**	9	3	**3x4x0,25b**	18
	Bus RS485	**4x0,25b**	(fourni)	1	**4x0,25b**	6
C2	Pompe peristaltique	**4x0,25b**	3			
	V3V temperature	**4x0,5**	3			
	3 x debitmetre	**2x0,25b**	3	1	**4x0,25b**	3
	9x capteurs de niveau	**2x0,25b**	9	3	**3x4x0,25b**	18
	Bus RS485	**4x0,25b**	(fourni)	1	**4x0,25b**	6
C3	Pompe peristaltique	**4x0,25b**	3			
	V3V temperature	**4x0,5**	3			
	3 x debitmetre	**2x0,25b**	3	1	**4x0,25b**	3
	9x capteurs de niveau	**2x0,25b**	9	3	**3x4x0,25b**	18
	Bus RS485	**4x0,25b**	(fourni)	1	**4x0,25b**	6

Nomenclature	longueur
Cable 3x0,5	23
Cable 4x0,5	9
Cable 2x0,25 blindé	48
Cable 4x0,25 blindé	117
Cable 6x0,25 blindé	3

5. Software

Software code is available on github: https://github.com/purrutti/FACEIT

a. PLC software

PLCs are Arduino-based industrial PLCs. The code is written in C/C++, and was developed using Visual Studio community 2019 with the vMicro extension and Arduino 1.8.13.

The code uses publicly available libraries from the community as well as self-made libraries.

It is divided into two codes :

- Master.ino: for the Master PLC
- Regul_condition.ino: for the slave PLCs

Here is a description of the main functions used in the loop:

i. RTC.read()

The PLCs are equipped with a RTC chip and battery to keep track of the date. Once set on commissioning, RTC.read() returns the current date and time.

ii. readMBSensors()

This functions loops through each sensor connected on the RS485 bus. Each Mesocosm has two sensors (O2 and Conductivity/Salinity), so each PLC has 6 sensors connected on its bus.

O2 sensors have addresses ranging from 10 to 12, for mesocosms 0 to 2 of the scenario, respectively.

PC4E sensors have addresses ranging from 30 to 32, for mesocosms 0 to 2 of the scenario, respectively.

Sensors are requested individually and in sequence. A request is made every 200ms, so each sensor is requested every 1.2 seconds.

iii. webSocket.loop()

This is a callback function responsible for dealing with the WebSocket communication.

The master PLC is the WebSocket server. It listens to slave PLCs requests and to the monitoring PC requests.

Requests are JSON formatted. They always contain the following leading fields:

- senderID: ID of the entity sending the request. Values can be:

ID	Description
0	Master PLC
1,2,3	Slave PLC
4	Monitoring PC

- condID: ID of the requested entity

- command: The command type of the request. Values can be:

Command number	Description
0	Request params: setpoints, PID settings…
1	Request data: measurement values, regulation outputs…
2	Send Params: a response to a « request params » request
3	Send Data: a response to a « request data » request
4	Calibrate sensor: a request for calibrating the specified sensor to the specified value
5	Request Master data: specific data measured by the master PLC (pressure & flowrates of general water input)
6	Send Master data: a response to a « request Master data » request

- They optionally can also contain a « time » field: Unix-like timestamp (number of seconds since 01-01-1970)

iv. regulationTemperature()

This function is responsible for the temperature regulation of the mesocosm. It sets the corresponding three-way valve position using a 0-10V analog signal.

The function first checks if the regulation is in « manual override » mode. If so, it applies the override setpoint.

If not, it reads the temperature measure in the mesocosm, compares it with the setpoint, and uses the PID settings to set the valve position.

v. regulationPression()

ONLY FOR MASTER PLC

This function is responsible for the pressure regulation of the mesocosm. It sets the corresponding three-way valve position using a 0-10V analog signal.

The function first checks if the regulation is in « manual override » mode. If so, it applies the override setpoint.

If not, it reads the pressure measure in the mesocosm, compares it with the setpoint, and uses the PID settings to set the valve position.

vi. regulationSalinite()

ONLY FOR SLAVE PLCs

This function is responsible for the salinity regulation of the mesocosm. It sets the corresponding three-way valve position using a 0-10V analog signal.

The function first checks if the regulation is in « manual override » mode. If so, it applies the override setpoint.

If not, it reads the salinity measure in the mesocosm, compares it with the setpoint, and uses the PID settings to set the valve position.

vii. checkMesocosmes()

This functions loops through every mesocosm every 200 ms and reads analog signals, ie flowrates and pressure readings.

viii. printToSD()

ONLY FOR MASTER PLC

Master PLC is equipped with a microSD card, on which data from all mesocosms is logged every 5 seconds, in one csv file per day. This is for security only, as the microSD card is not easy to remove from the PLC casing. It should not be removed before the end of the experiment.

This may be useful if a communication failure occurs between the Master PLC and the Monitoring computer, as data will not be retrieved by the PC during this period. The SD card will contain the missing data and will allow to fill in the blanks.

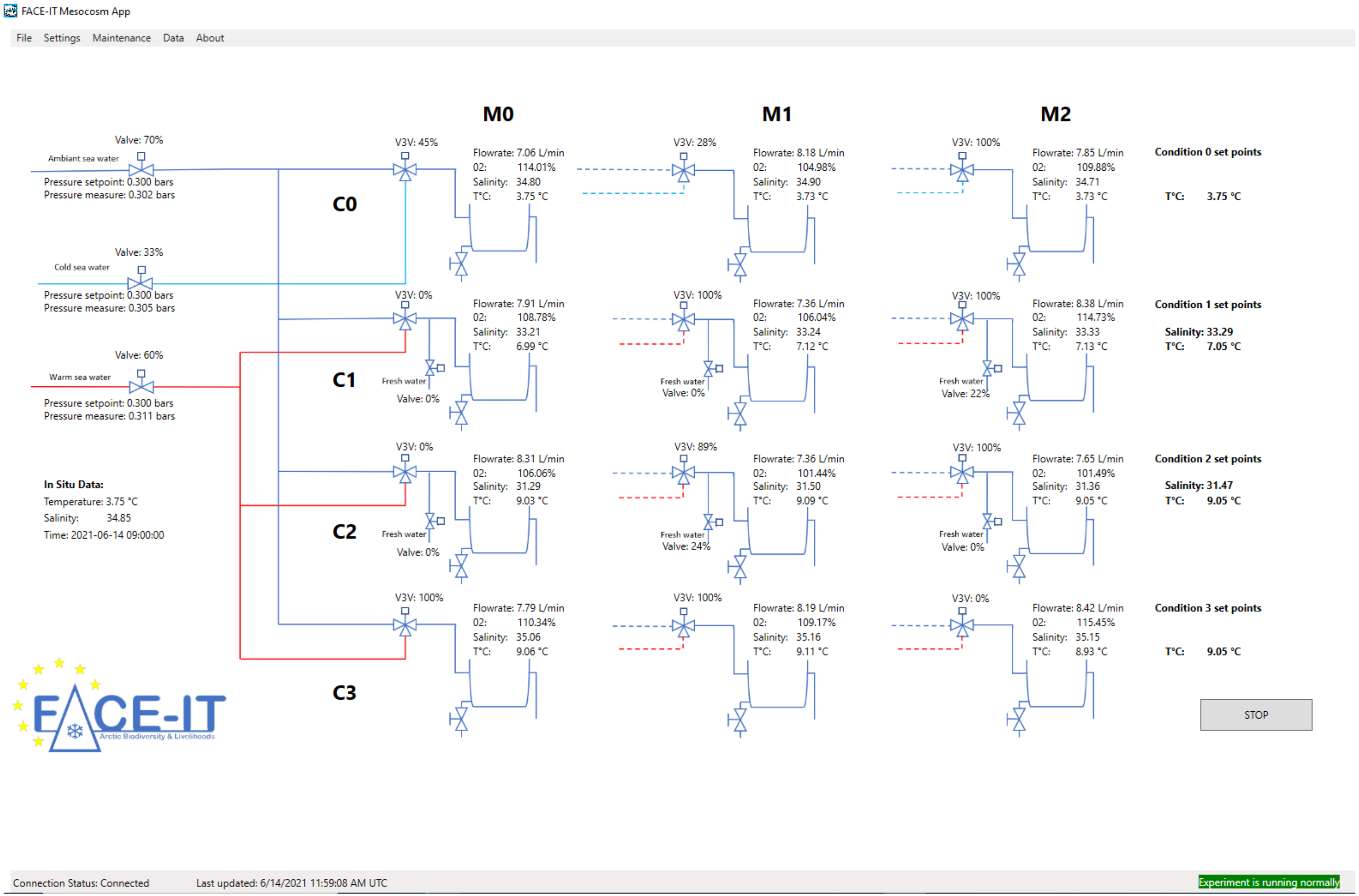
b. PC application

The FACE-IT Mesocosm Experiment PC application is a software developed in C# for communicating with the PLCs.

Its purposes are:

- Live monitoring of the experiment
- Experiment control and settings
- Data Logging

i. Main Window



The main window shows the 12 mesocosms and their piping connections. It also shows three general seawater inlets (Ambient, Cold, Hot).

In the bottom of the window, a status bar shows the current connection status (connection with the PLCs), the date and time of the last communication packet received from the master PLC, and the status of the experiment (started / stopped).

On the left is shown the pressure setpoints and the pressure measures for each seawater inlet. The valve opening percentage is also shown.

In addition, the in-situ Data (temperature and salinity) received from the ferrybox is shown just below, along with the date of the last value. The in-situ temperature measure is used as a temperature setpoint for the control condition, and the in-situ salinity measure is shown for information only. This data is updated every hour (in general).

For each mesocosm, flowrate (L/min), O2 concentration (%), salinity (g/kg) and temperature (°C) are shown. Temperature mixing valve and fresh water valve openings are also shown.

For the control condition, we show the temperature setpoint value

For the other conditions, we show the temperature setpoint and the salinity setpoint values.

ii. Menu bar items

1. File

The « File » Menu bar items shows:

- A Connect / Disconnect button. Allows to manually connect or disconnect to/from the PLCs. It is not advised to use it since connection is automatic.
- An exit button. Guess what it does!

2. Settings

The « Settings » Menu bar item shows:

- An « Application settings » button. Displays the Application settings window
- An « Experiment settings » button. Displays the Experiment settings window

3. Maintenance

The « Maintenance » Menu bar item shows:

- A « Calibrate sensors» button. Displays the Calibration window
- A « Communication Debug» button. Displays the Communication Debug window

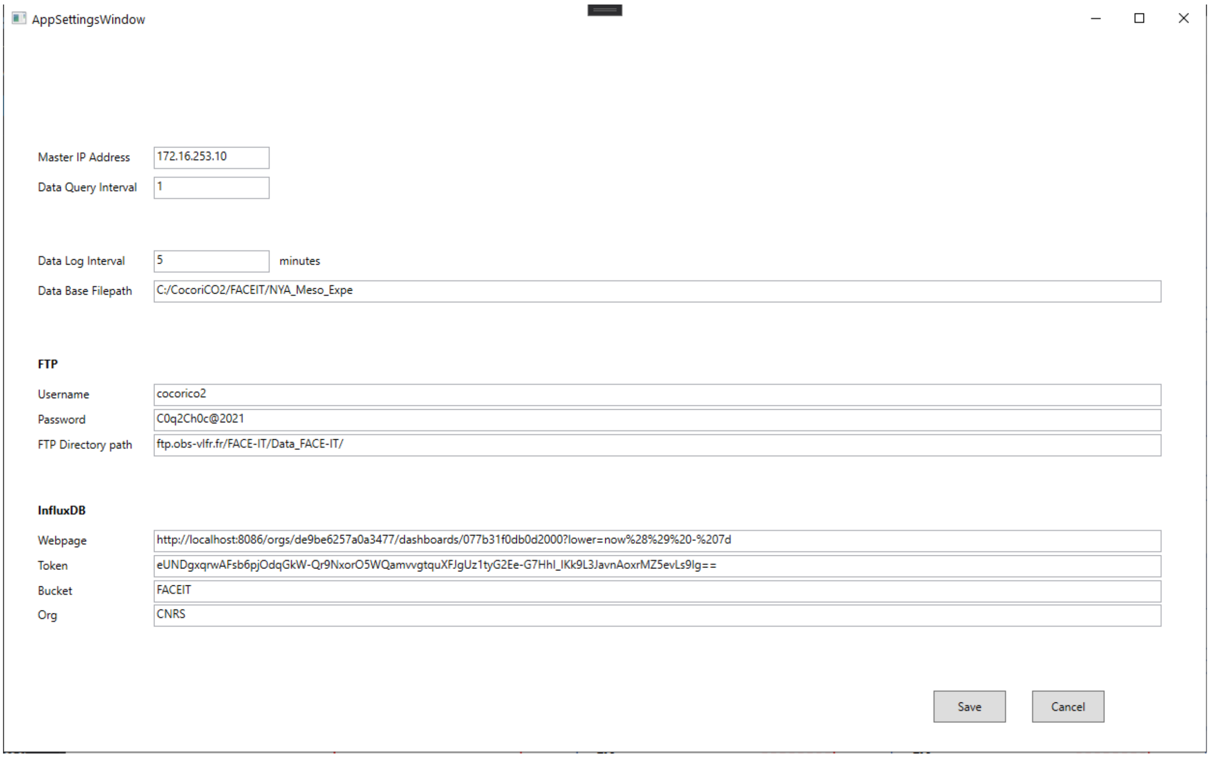
4. Data

The « Data » Menu bar item shows:

- A « Live Monitoring» button. Not yet implemented!

- A « Historical Data» button. Displays FACEIT Experiment Ny Alesund Data web page : http://www.obs-vlfr.fr/~gazeau/FACE-IT/FACE-IT.html

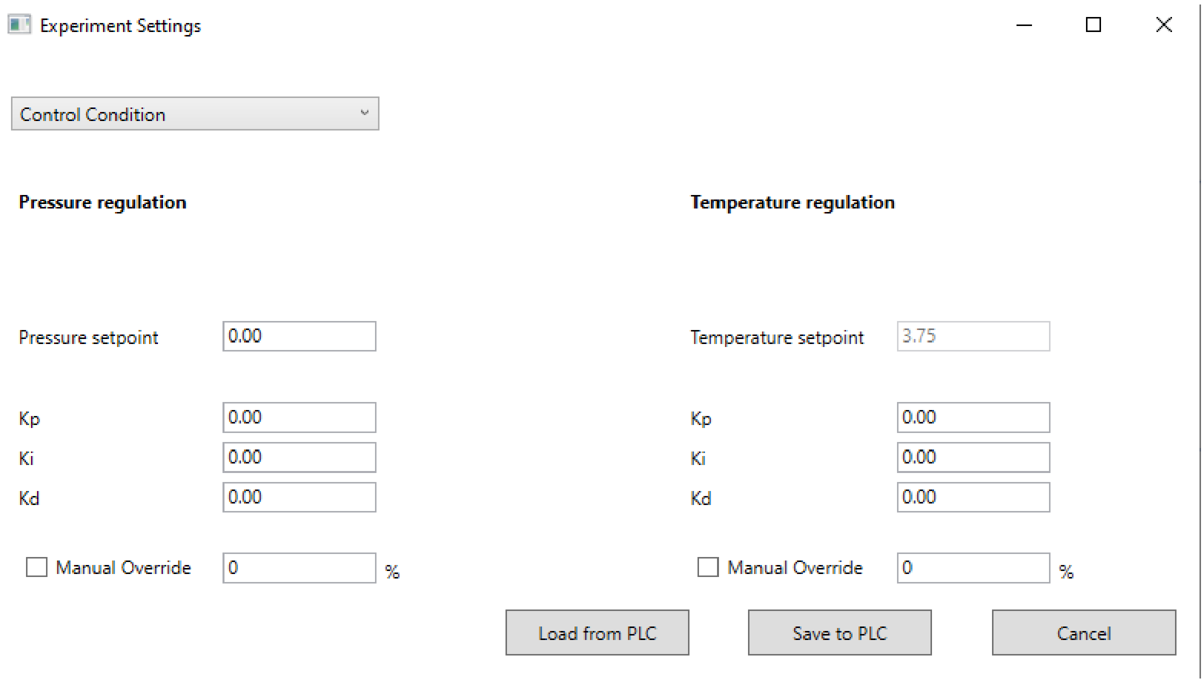
iii. Application settings



All the settings of the « App settings Window » are stored on the computer running the app.

- Master IP address: The IP Address of the Master PLC (centralizing all the data)
- Data Query Interval: Number of seconds between queries from the app to the master PLC
- Data Log Interval: Number of minutes between logs to file
- Data Base File Path: Directory and base filename of the csv data files. One file per day will be created, Date will be added to this base filename (e.g. NYA_Meso_Expe_2021_06_21.csv)
- FTP Username, Password, Path: FTP settings for sending the data file every hour.
- InfluxDB Settings: For Live Monitoring and local storage of the data. Not yet implemented!

iv. Experiment settings



This window allows to tune the regulation of the experiment. It allows to set the setpoints and Kp, Ki & Kd parameters for the regulation. It is also possible to override the regulation and set the valve openings to a specified value (between 0 and 100%).

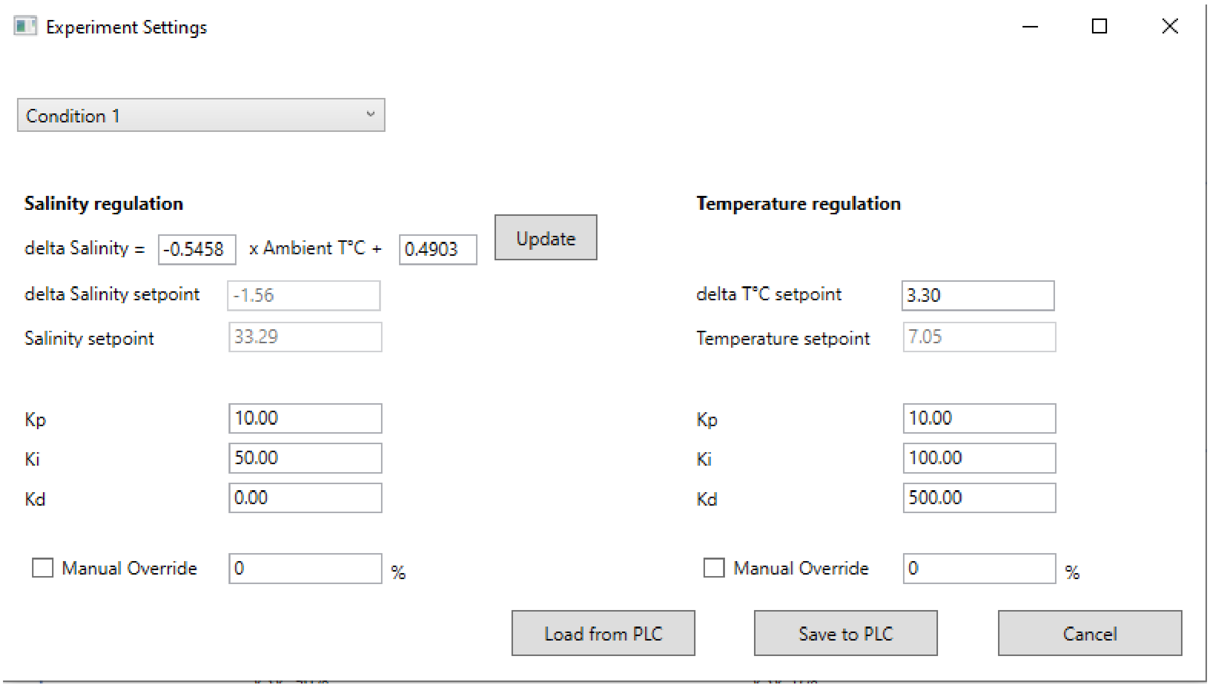
First, in the top left combo box, choose the condition you want to tune.

For the control condition, set the pressure setpoint for the 3 water inlets, and the Kp, Ki and Kd coefficient for their regulation.

The control condition temperature setpoint is given by the data received from the ferrybox.

Once you set all the parameters, click the « Save to PLC » button to send the values to the corresponding PLC and save the data.

The « Load from PLC » button allows to load the settings from the PLC (!), but this is done automatically. Use it to make sure your settings have been properly sent and acknowledged by the PLC.

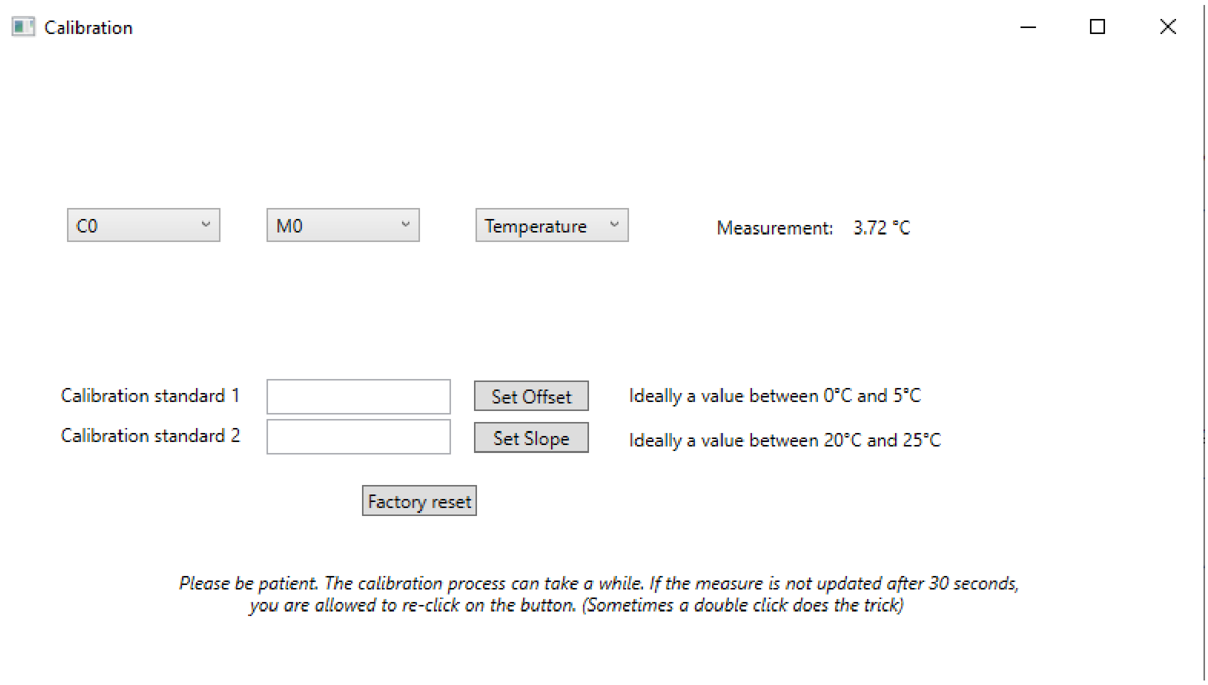


For conditions 1 and 2, the salinity setpoint is calculated based on a delta Salinity, itself calculated by a linear formula. Enter the coefficients and click update to calculate the delta Salinity.

Set the delta T° setpoint in the top right text box.

The salinity and temperature setpoint are calculated by adding the delta to the control condition setpoint, ie the ferrybox measures.

v. Sensor calibration



The calibration window allows to calibrate:

- The temperature on the Conductivity sensor
- The conductivity on the Conductivity sensor
- The Oxygen % on the oxygen sensor

Select the Condition, the mesocosm and the sensor you want to calibrate.

Place the sensor in a low value standard solution, enter the value in the first text box and click « set offset ». Wait for the measurement to change to the value you entered.

Then place the sensor in a high value standard solution, enter the value in the second text box and click « set slope ». Wait for the measurement to change to the value you entered.

If you made a mistake, you can always come back to factory settings by pressing the corresponding button.

As stated, please be patient, the communication process for sensor calibration is rather long. It usually takes around 5 to 10 seconds, but it can sometimes take longer, or even do not respond. In that case, wait 30s before retrying.

Note on oxygen sensor calibration: You can only enter 0 for low value, and 100 for high value.

Note on conductivity calibration: You can only calibrate the conductivity value, as the salinity measure sent by the sensor is calculated based on the conductivity. However, the sensor shifts the conductivity value to a conductivity at 25°C before sending it. The conductivity value in uS/cm shown in the app is therefore the conductivity at 25°C, not the one at the measured temperature. *Be advised, and be careful.*

vi. Communication Debug

For troubleshooting only: it allows to check the request sent by the App to the master PLC, and its response.