GAIN Green Aquaculture Intensification SUMMER SCHOOL

Data assimilation and its application to the smart management of oxygen supply

Edouard Royer
Ca'Foscari University of Venice
edouard.royer@unive.it

GAIN SUMMER SCHOOL

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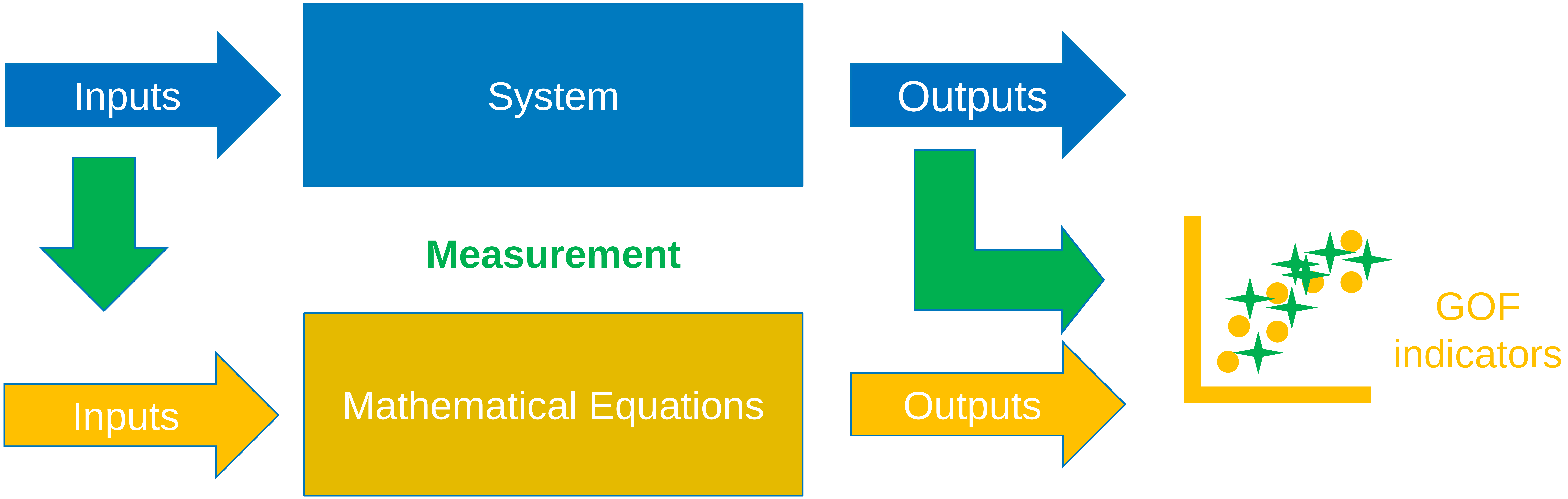
WHO IS THE SPEAKER ?

- **Electrical Engineer from INSA Lyon (France)**
- **Jobs experience as Software Engineer and Technical Project Manager in several fields (aerospace, manufacturing)**
- **Data Scientist for Aquaculture since 2016**
- **H2020 GAIN (UNIVE) from April 2019**

WHAT WILL HE TALK ABOUT ?

- **Modelling and GAIN approach**
- **Dissolved Oxygen (DO) model for raceway**
- **Data Assimilation (DA)**
- **DA and DO**
- **Examples of applications**

Modelling approach - Principles



GAIN modelling approach : Precision Fish Farming (PFF)

- A paradigm that comes from agriculture
  - **Precision Livestock Farming** (PLF)
  - **Hardware** => Low-cost sensors, Web access, IoT, processing capacity
  - **Software** => Data science, user-friendly languages (Javascript, Python, R)

- PFF aims (Fore et al., 2018)
  - Improve **accuracy, precision and repeatability** in farming operations;
  - Facilitate more autonomous and continuous **biomass/animal monitoring**
  - Provide more **reliable decision support**
  - **Reduce dependencies on manual labour** and subjective assessments, and thus improve staff safety

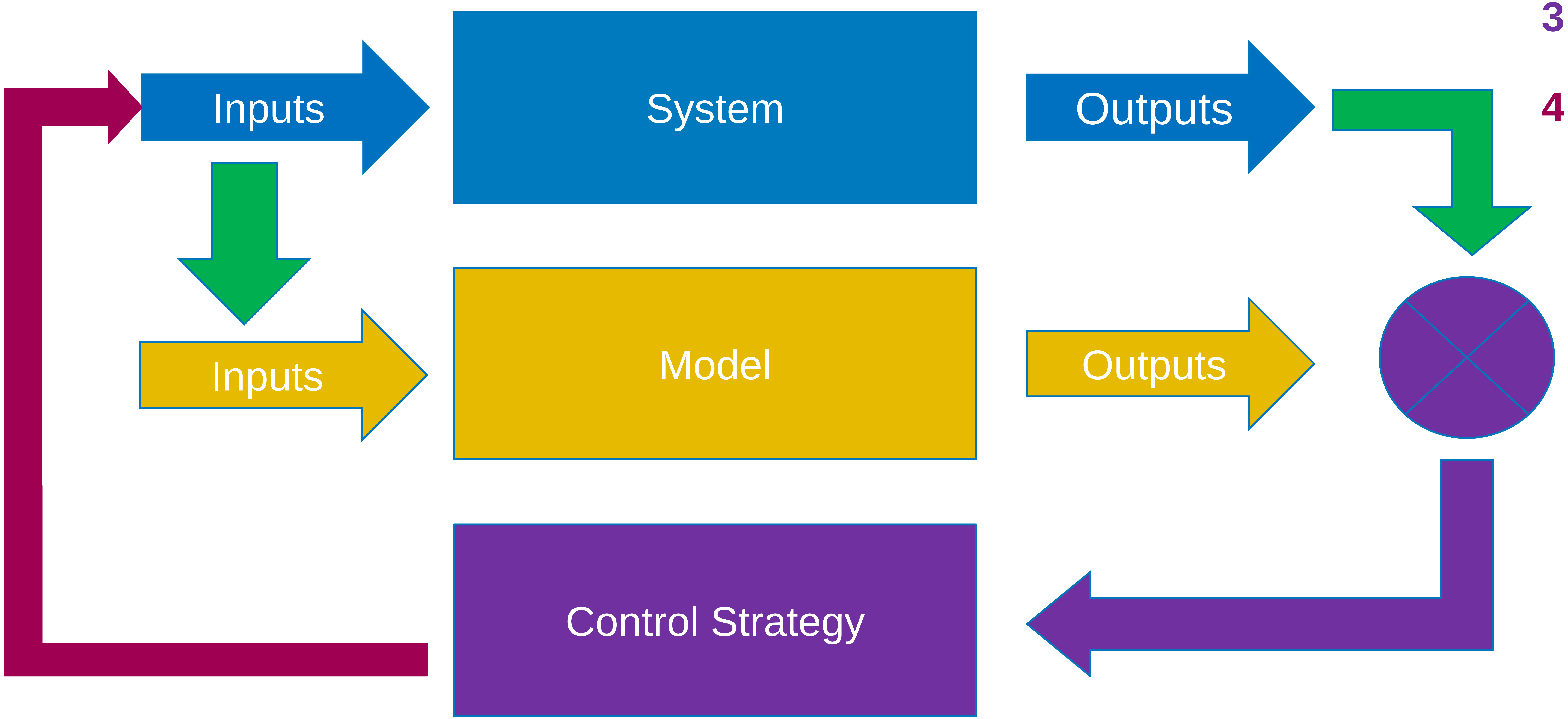
GAIN modelling approach : PFF steps

1 - Observe

2 - Interpret

3 - Decide

4 - Act

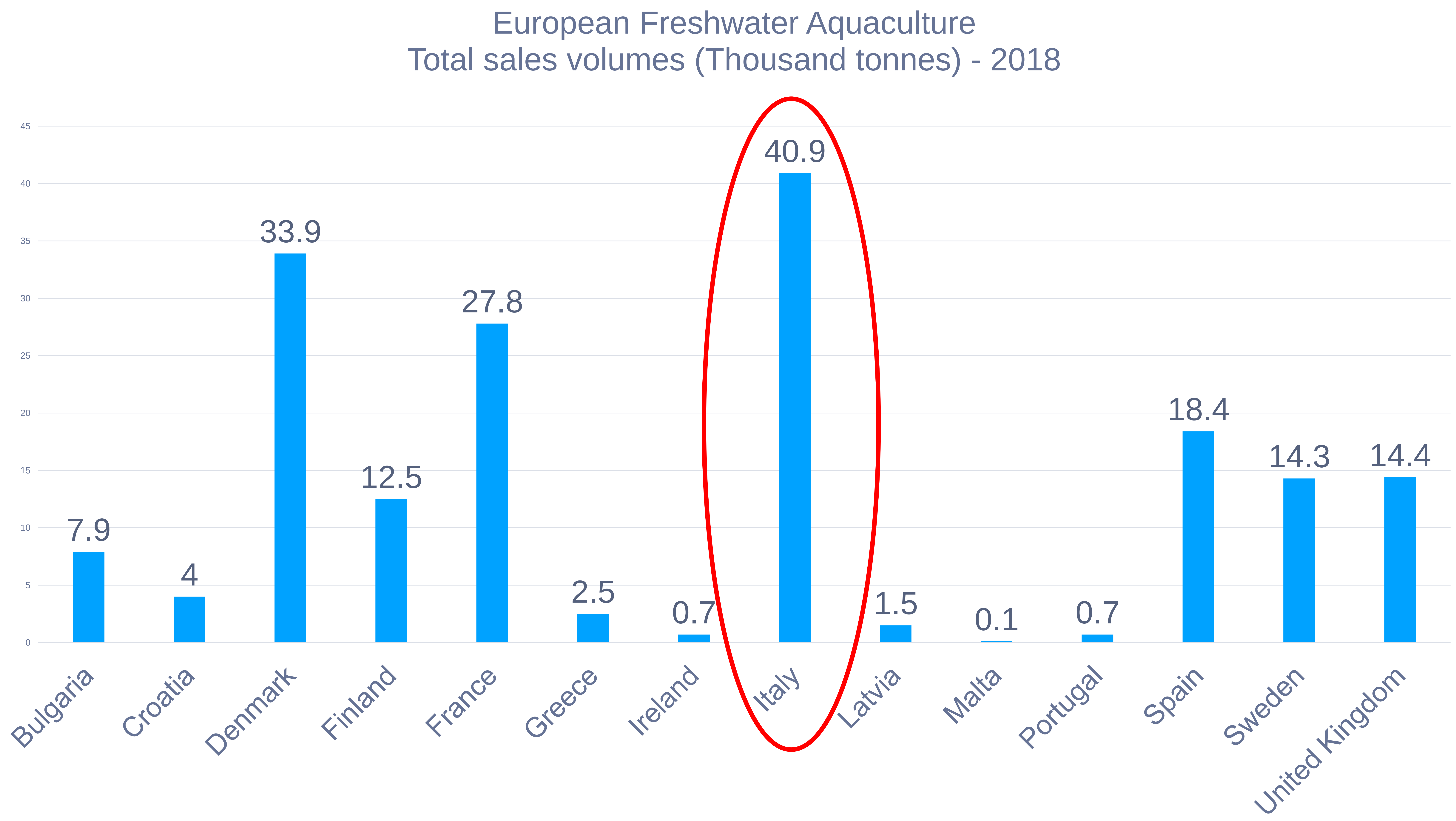


Modelling approach - What kind of model ?

- Physical model (model-oriented)
  - Mathematical **equations**
  - Tried to **describe the physical process**
  - Hypothesis regarding the various processes at stake and their relative importances with regard to the dynamics of the output

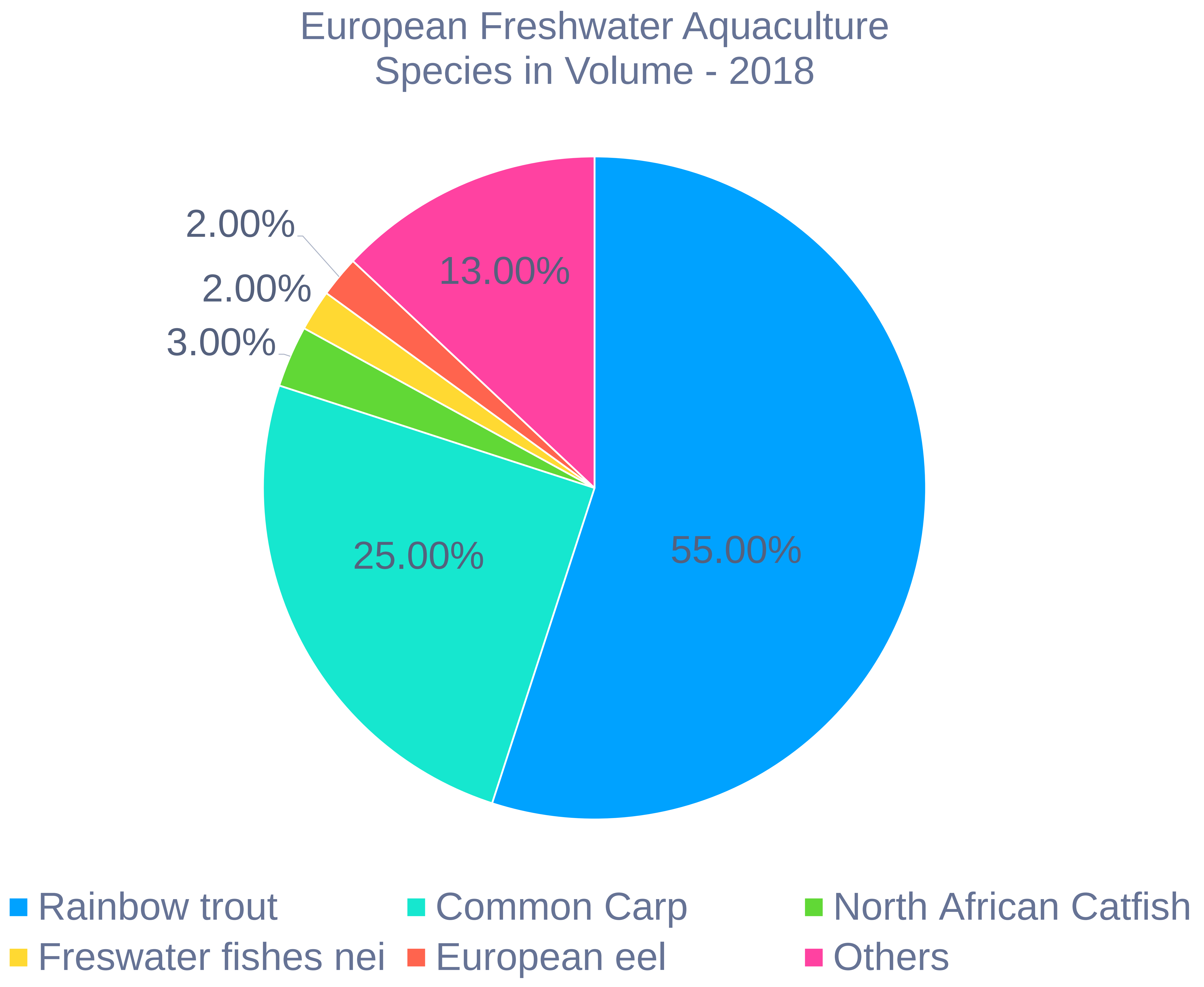
- Data driven model
  - Mathematical **equations**
  - Try to find some relation between inputs and outputs using **statistical** approaches
  - Choice of methods and **complexity** of the relationship

Case Study – Freshwater aquaculture in Europe



Source:
STECF 2018

Case Study - Freshwater aquaculture species



Source:
STECF 2018

Italian Case Study : Rainbow trout in Italy

- Rainbow trout production
  - Constant increase from the 1960s–1990s
  - Peak in 1997 (50 000 tons)
  - Stable around 40 000 tons in the last decade
  - Production mainly in the Northern Italy (water from the Alps)

- Companies and products
  - Most companies are medium-small size companies, often family-run
  - Fish less than 500g as «gutted head on»
  - Larger fish converted into process products (fillets, hamburgers, skewers)

Italian Case Study : Fratelli Leonardi Farm

- The company
  - Familial business
  - Around 10 employees
  - 3 different production sites

- Farming premises in Preore
  - 7 Raceways / flow-through systems
  - 200m long, 8m wide, 0,8m deep
  - Water from Sarca River

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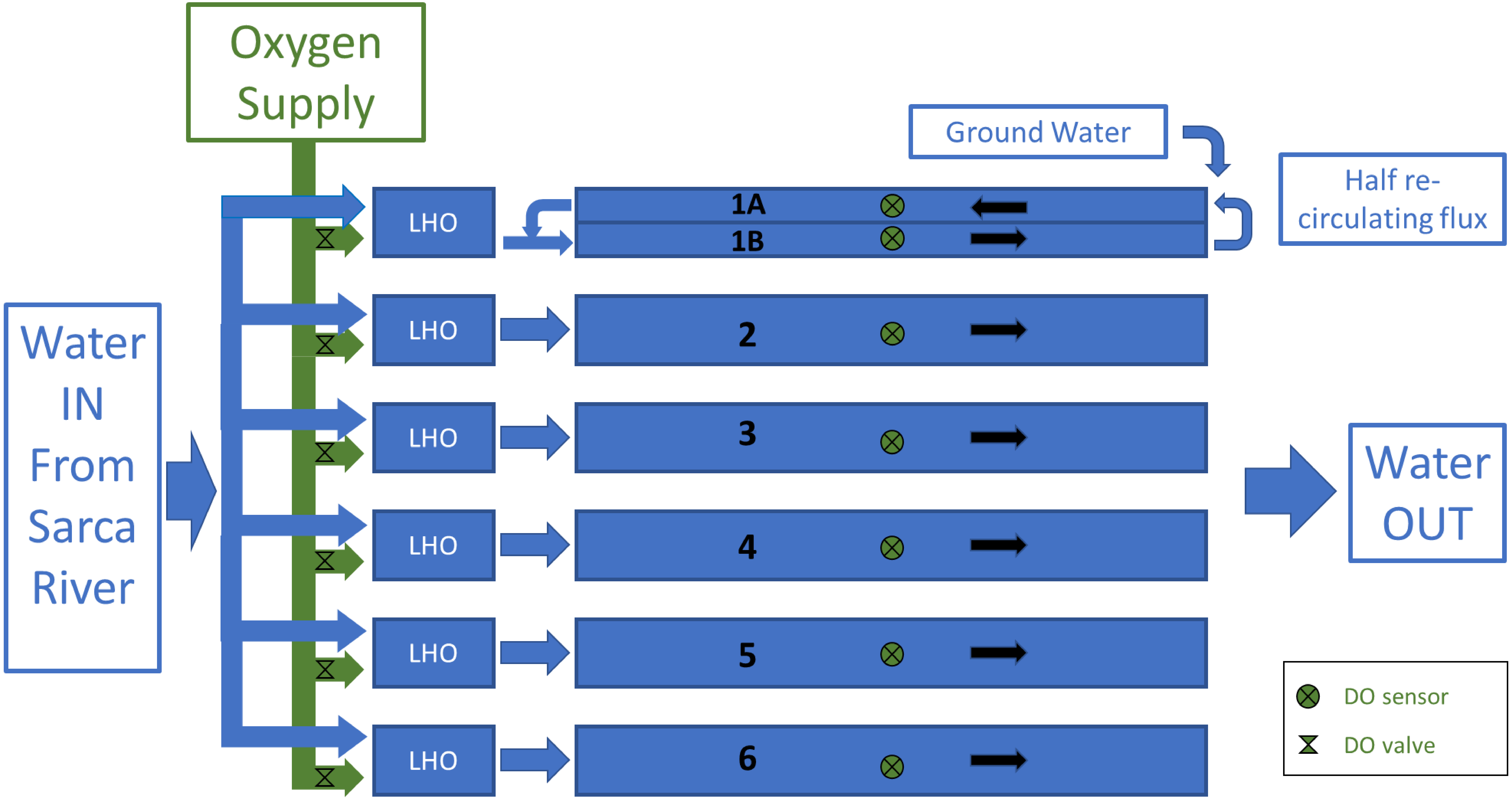
Italian Case Study : Raceways



DO Model – Oxygen in freshwater aquaculture

- DO concentration in water
  - Water from ground needs to be enriched because of low DO concentration
  - Water from streams can present high variations following seasons

- Means of DO concentration improvement
  - Many **different systems** allow to increase DO concentration in water
  - **Aeration** = mechanical actions
  - **Oxygenation** = liquid oxygen supply

DO Model – System definition

- System = **DO concentration within the raceway**
  - Inputs : Water, Oxygen supply, biomass, air exchange
  - Output : DO in the effluent

- Description of the **physical process**
  - Mass balance of DO
  - List of contributors
  - Differential equation

DO Model – Hypothesis

- Complete mixing of water within the raceway
  - Biomass uniformly distributed
  - Raceway as a «point»

- No significant primary production
  - Water residence time (48 min) means good replacement (no stagnation)
  - Water from Sarca river very «clear»

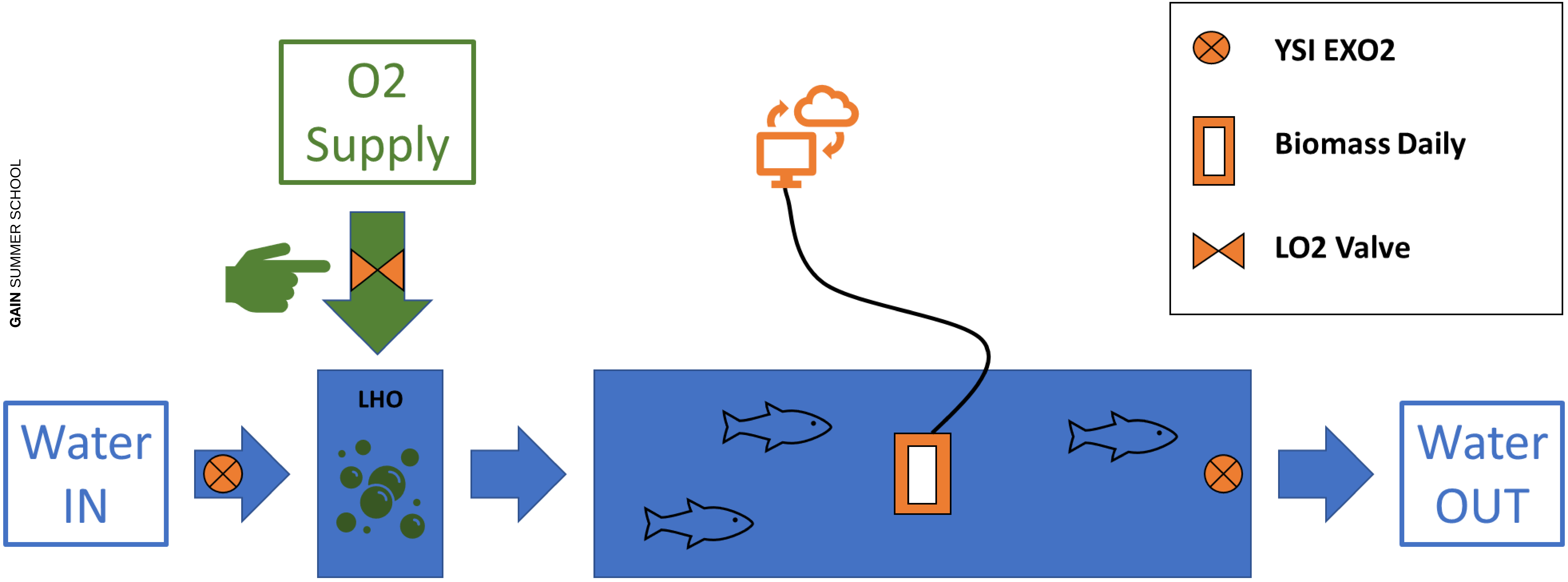
- Echange with the atmosphere: Reaeration

DO Model – Differential equation

$$\frac{\partial DO}{\partial t} = \frac{Q}{V} * \frac{\partial DO_{in}}{\partial t} - \frac{Q}{V} * \frac{\partial DO}{\partial t} + O2\ Supply + Reaeration - Fish\ Respiration$$

Water IN	Water OUT	O2 Supply	Reaeration	Fish Respiration
$\frac{Q}{V} * \frac{\partial DO_{in}}{\partial t}$	$\frac{Q}{V} * \frac{\partial DO}{\partial t}$	Provided by farmer	$k_{rear}(DO_{sat} - DO)$	$R_m * e^{p_k*(T-15)} * N * W$
+	−	+	+ / −	−

DO Model – Experimental PFF System

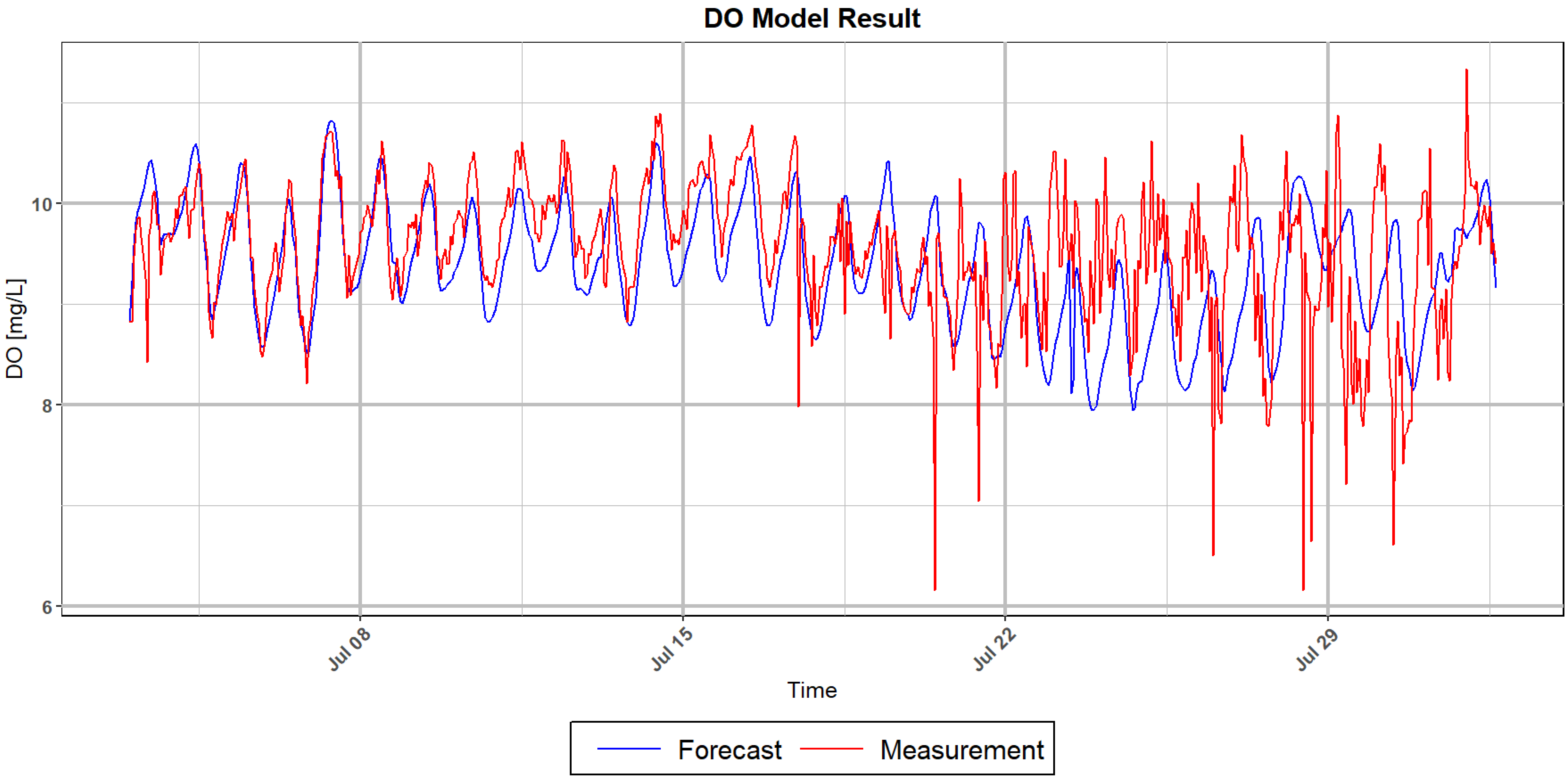


DO Model – Calibration

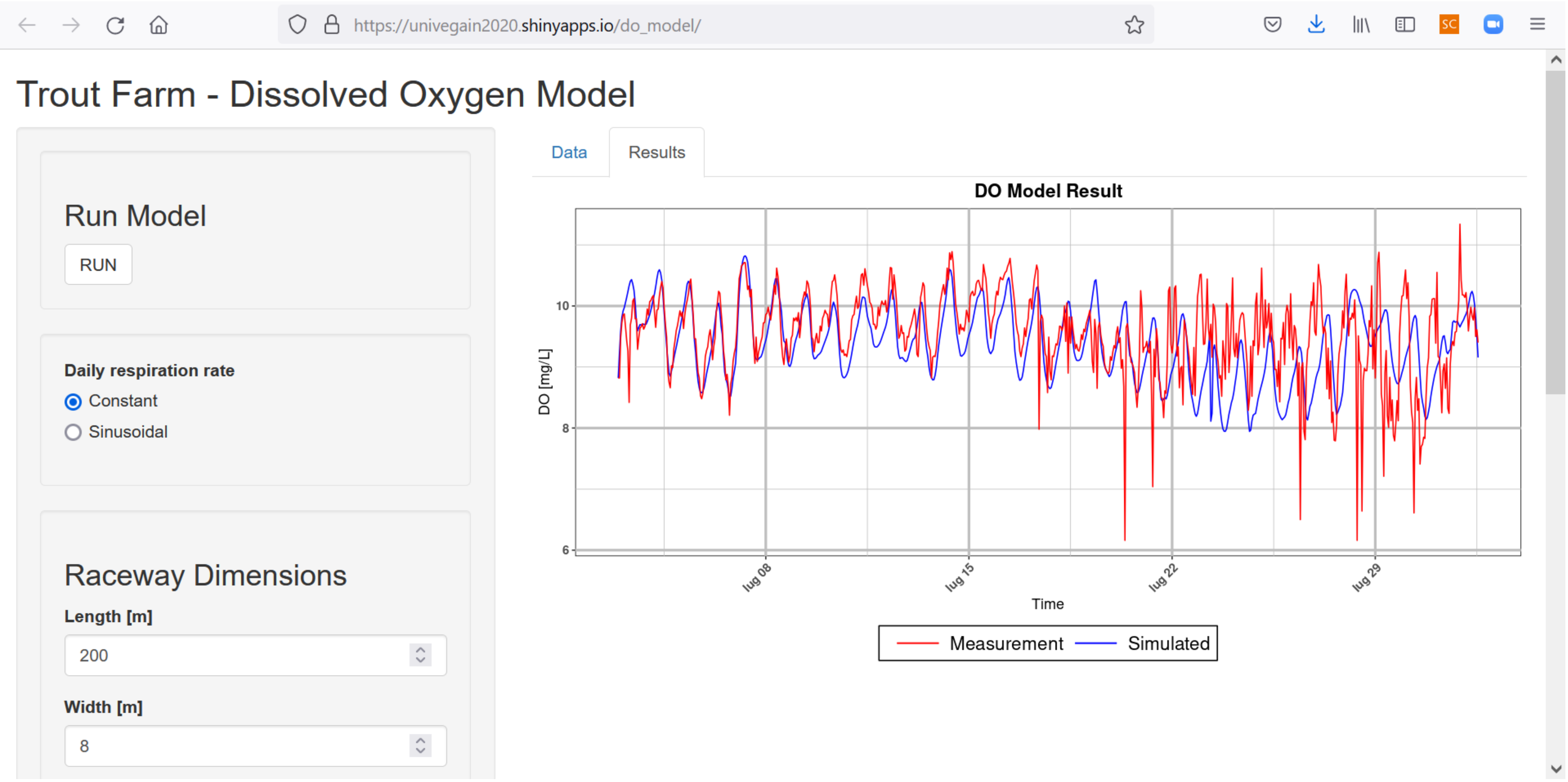
- Fish respiration rate calibration
  - Trout respiration rate available from litterature
  - But mostly measured under «artificial» conditions
  - What about «real conditions» respiration rate ?

- Calibration process
  - Search for Rm that minimize a «Goodness of Fit» function
  - Creation of synthetic series from sampled one => parameter dispersion

DO Model – Results



DO Model – Web Application



Note that the real sampled data (red curve) will remain the same !

- Web application of DO model available at: https://univegain2020.shinyapps.io/do_model/
- Can be useful to illustrate the effect of several parameters on the simulation output

Data Assimilation - Principles

- What is it ?
  - It consists in combining model predictions and observations to improve the estimation of the state of a given system as it evolves in time.
  - It allows then a more reliable forecast
  - Model-oriented AND data-driven method (model + measurements)

- Where does it come from ?
  - Mathematics and engineers
  - Meteorology (reliable weather foreacts) and space in the 1960's

- Where it is used ?
  - Today widely used in several fields (oceanography, meteorology, space, ecology, …)

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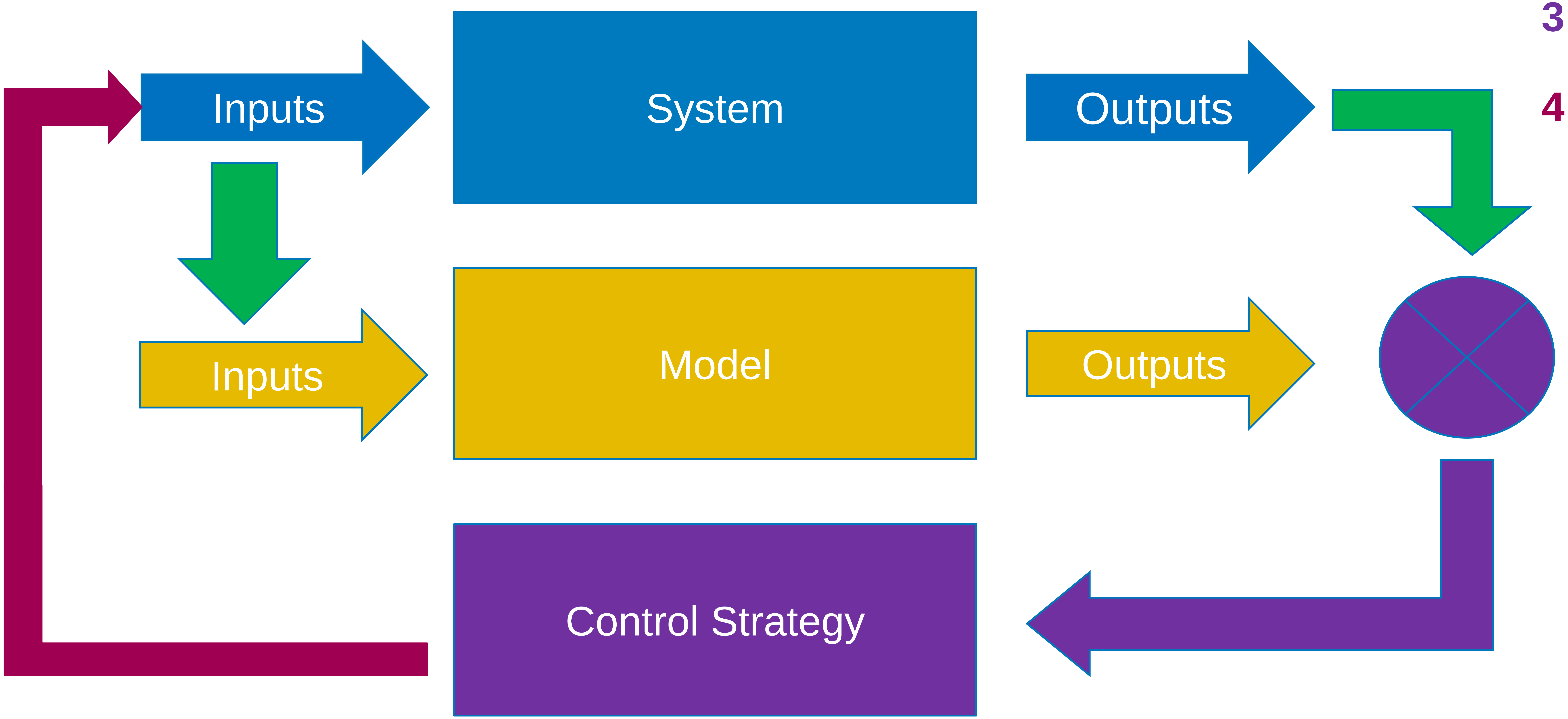

Data Assimilation - Principles

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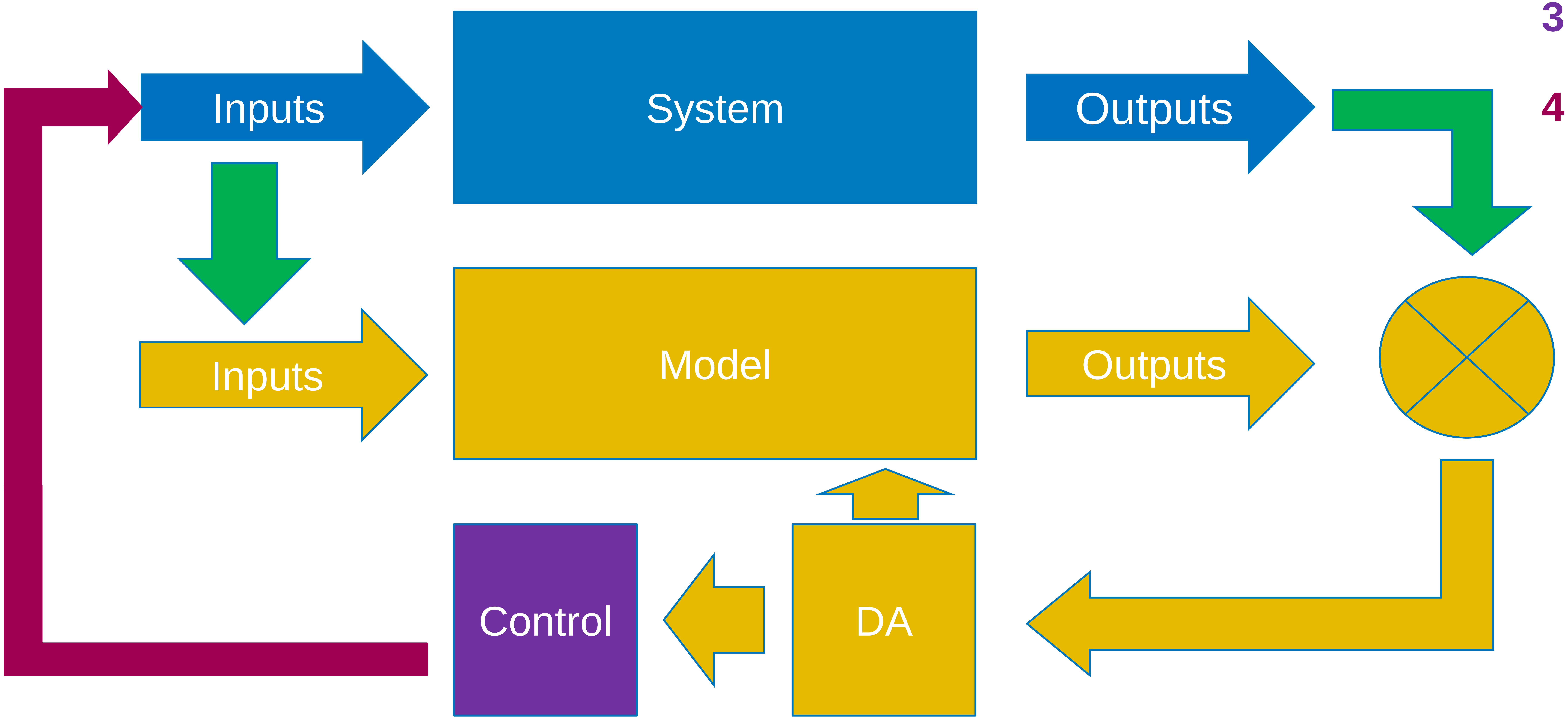


Data Assimilation – Kalman Filter

- A bit of history …
  - Kalman filter was developed in the 1960's by **mathematicians/engineers**, one of them being Rudolf E.Kalman
  - A **NASA** engineer (Stanley F. Schmidt) understood it could be useful for **Apollo** trajectory and implemented it within **navigation computer**.
  - Today **still in use in aerospace** (Ariane 5 GNC, Rendezvous and Docking)

- Why to choose it ?
  - **Proven methodology**: one the most widely used DA methods
  - **Versatility**: Several formulations in order to deal with different types of problems (Linear/Non-linear, Continuous/Discrete)

Kalman Filter

- Principles
  - Some **parameters** of the model can be treated as **stochastic variables**
  - **Non-observable variables** can then become variables (included in the **state vector**)
  - Every new observation is used to «correct» the forecast but also the parameters itself

- Consequences
  - Forecast **improvement**
  - Parameters **changing in time**

DO model and Kalman Filter

- Augmented state
  - To take into account the **effect of neglected processes** in fish respiration rate description, respiration rate was chosen to be add to the state vector
  - **Rm** is then no more constant but can vary with time following KF algorithm

- Filter steps for every new observation
  1. DO value at new time is **forecasted** from the last one using DO model (**propagation**)
  2. New DO observation is **compared** with its forecast. This difference is **weighted**
  3. Rm is **adjusted** according to this weighted difference

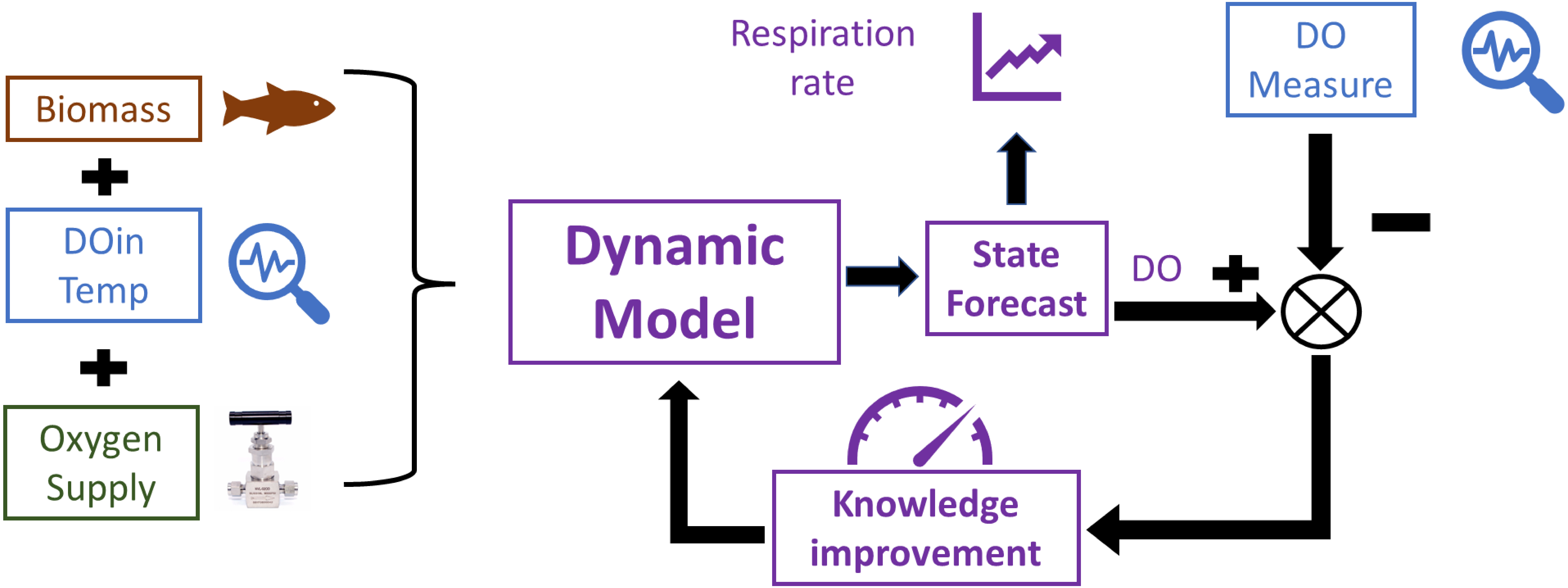
Fish Respiration

$$R_m * e^{p_k * T} * \boldsymbol{N} * \boldsymbol{W}$$

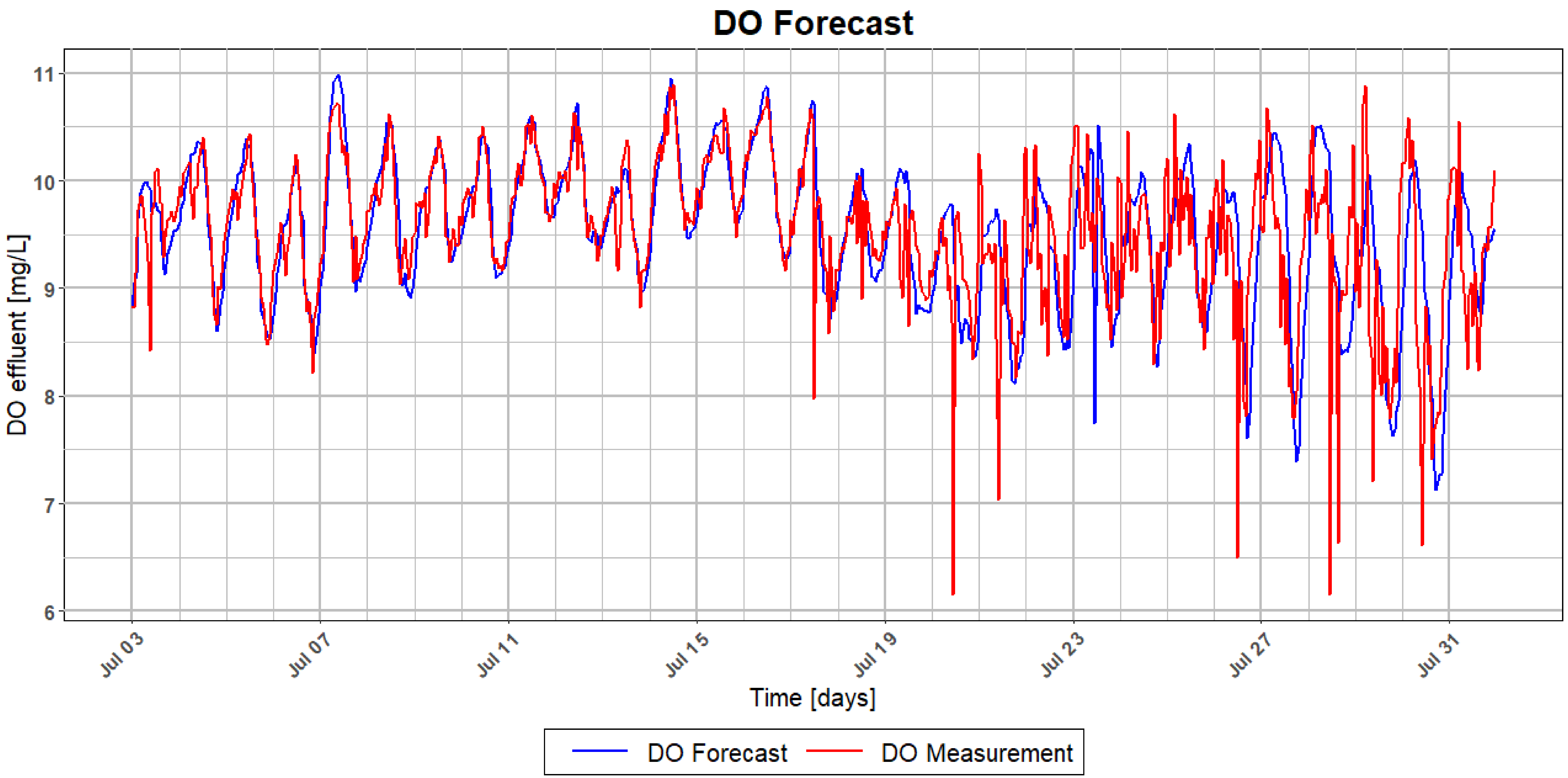
Weight

Temperature

KF Algorithm – Schematic View



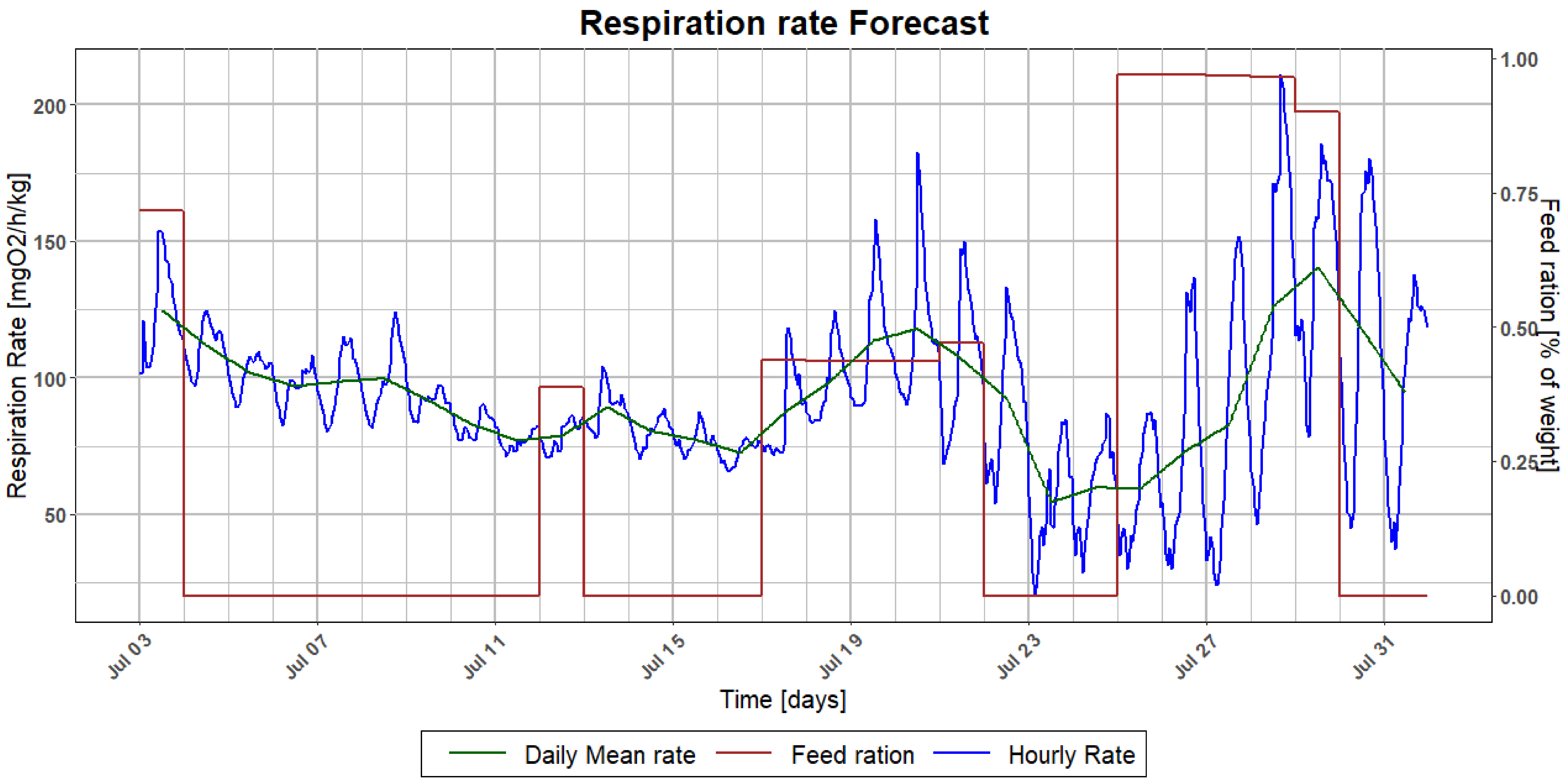
KF for DO: Results



DO Forecast improvement

- Better performance of the KF forecast with respect to DO model forecast: (0,37 mg/L v/s 0.51 mg/L)
- Good performance even with high variability

KF for DO: Results



Respiration Rate Estimation

- Mean specific respiration rate : 95 mgO2/(kg.h)
- Daily oscillations due to circadian rhythm
- Daily averages are related to the feeding regime

KF for DO – Applications - 1

- DO Supply smart control
  - More reliable forecast of DO concentration can be of huge interest for DO supply control
  - Today DO Supply is manualy controlled: the valve setpoint is decided by the farmer and remains constant for long periods (months)
  - A reliable forecast of next hour value could be used to dynamically adapt

- Benefits
  - Cost savings (Liquid oxygen is one of the main costs after feeding and labour)
  - Animal welfare as it can be used to prevent some quick changes in DO levels that could be harmful for the fish

KF for DO – Applications - 2

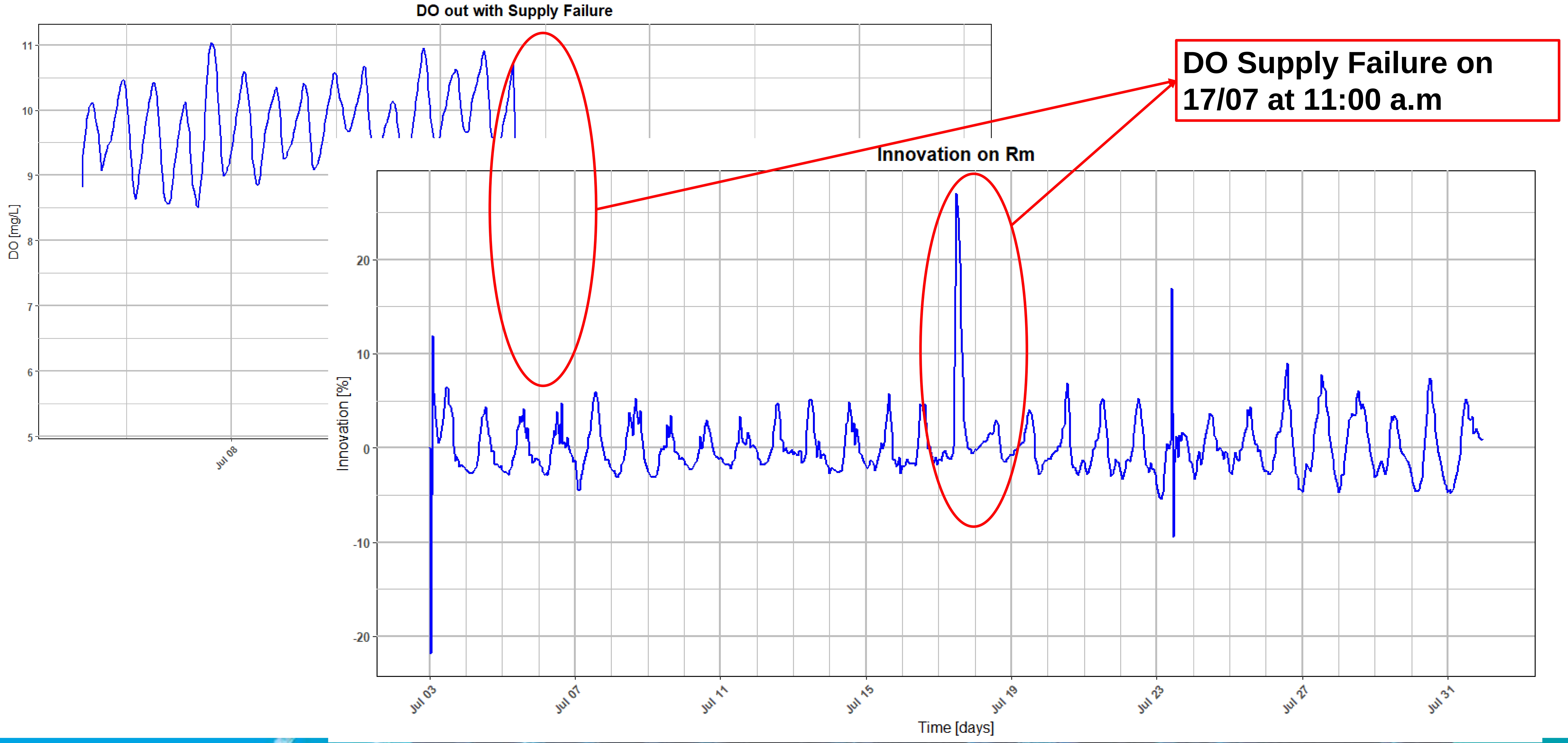
- Effluent Early warning
  - More reliable forecast of DO concentration means an interesting monitoring of the water quality in the effluent
  - Water is then thrown back to the river and an alert could emitted when DO concentration falls below a critical threshold

- Benefits
  - Preserve the river natural ecosystem

KF for DO – Quality Control - 3

- Comparison between forecast and measured
  - The amplitude of the «correction» computed by the filter can be used to detect anomalous situations
  - Unexpected sudden changes correspond to potential concern with the system
- Benefits
  - Alert the farmer in case of anamalous situation detected
  - Prevent from huge consequences of hardware concerns: probes failure, DO supply system failure

KF for DO – Quality Control - 3



Conclusions – For the engineer/scientist

- Online DA benefits
  - Increase forecast capacity of simple models
  - Open the way to smarter control
  - Can allow anomaly detection
- Offline DA benefits
  - Improve the description and thus the understanding of the process itself

Conclusions – For the farmer

- Benefits
  - The **pertinent oxygen quantity** is supplied at every moment
  - Failures can be detected allowing to **anticipate potential damages to the biomass**
  - Water quality in the effluent is better monitored to **avoid negative consequences on downstream ecosystem**

COST SAVINGS

THANK YOU FOR YOUR ATTENTION !

edouard.royer@unive.it