Implementation and industrialization of a **deep-learning model** for **flood wave prediction** based on grid weather forecast for hourly **hydroelectric plant optimization**: case study on **three alpine basins**

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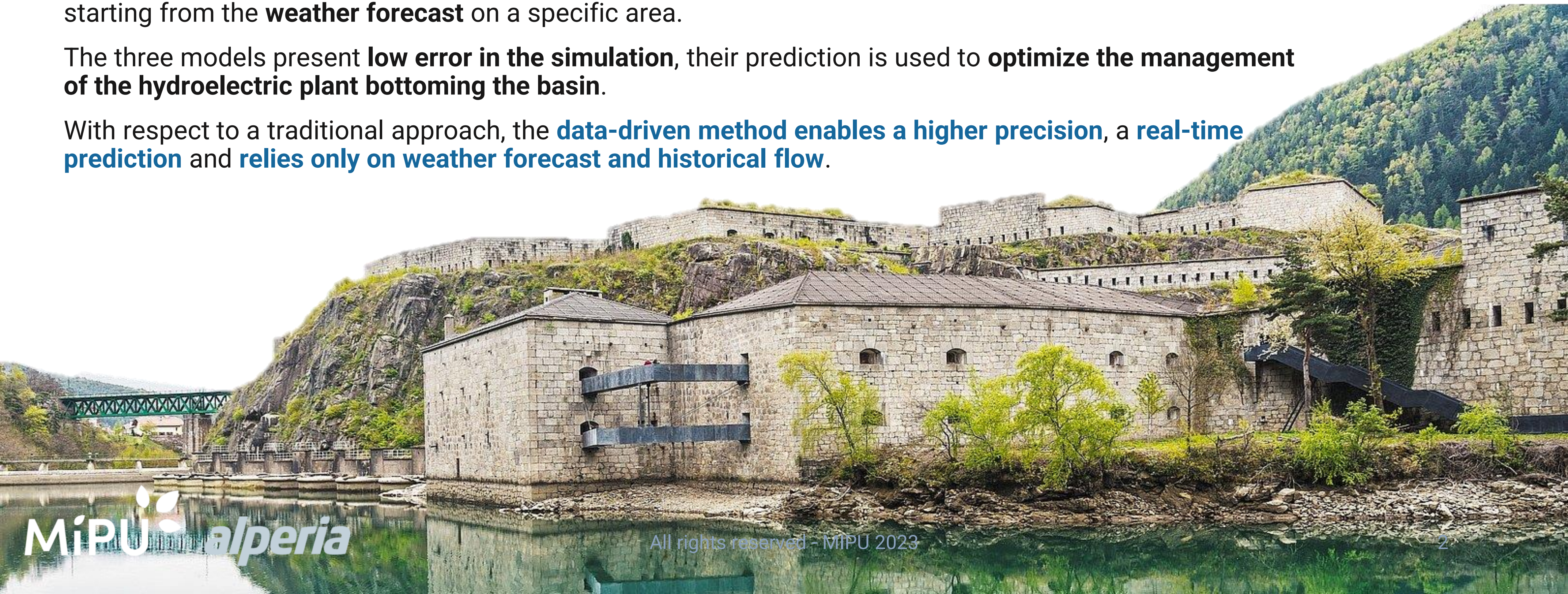
Abstract

In the present study a **data-driven approach** is used to simulate the behavior of **3 alpine basins** for **hydroelectric energy production.**

A **deep feedforward neural network** is used to predict **3 different scenarios of flood wave**, simulated starting from the **weather forecast** on a specific area.

The three models present **low error in the simulation**, their prediction is used to **optimize the management of the hydroelectric plant bottoming the basin**.

With respect to a traditional approach, the **data-driven method enables a higher precision**, a **real-time prediction** and **relies only on weather forecast and historical flow**.

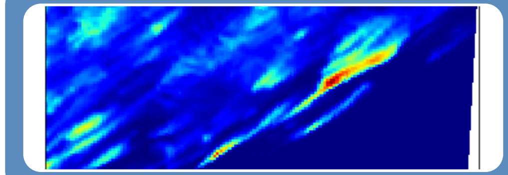


Introduction

On the alpine chain the last years have been characterized by droughts and cloudbursts with an increased intensity in terms of precipitations.

In this scenario, the flood wave prediction is becoming more and more challenging

- The soil changes properties with an increased speed and the behavior of alpine basins becomes difficult to predict.
- This situation is being registered not only on the Alps, but on many other mountain chains.

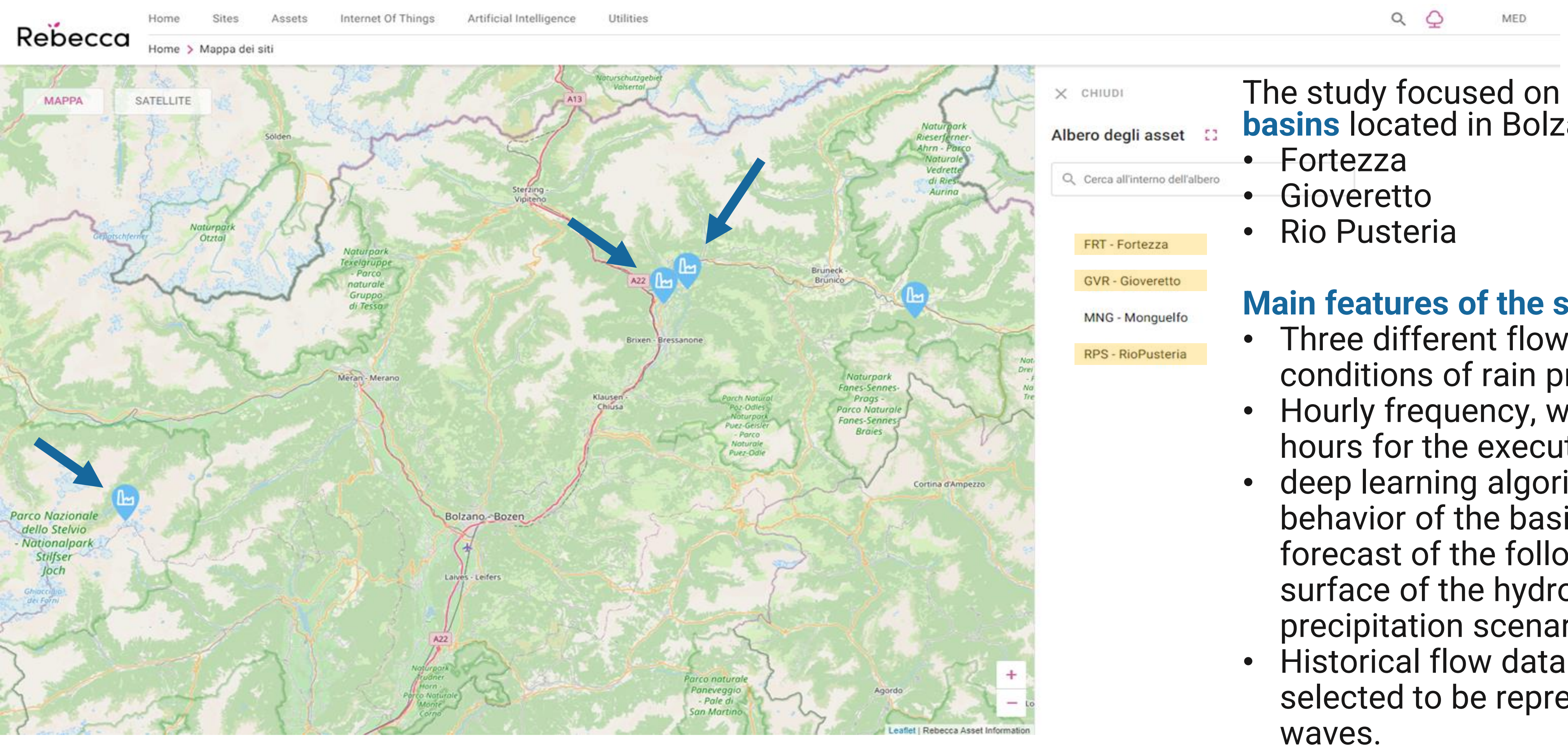


Deep learning has proven to be an efficient method to predict short and medium term flow for river basins with R2 higher than 90%.

- A specific study from Innsbruck University focused on an alpine basin, confirming the possibility to model the flood wave in the basin starting from historical rain registration [8].
- None of the deep learning solution have still been industrialized to provide real time prediction based on weather forecast, in order to manage consequently a hydroelectric plant in order to maximize the power production and minimize risk an environmental impact of the flood.

The present study starts form existing researches to implement a deep learning model flexible enough to be used in real-time prediction and efficient enough to enable the hydroelectric plant management based on its predictions.

Method



The study focused on **3 different hydrographic basins** located in Bolzano area, Italy:

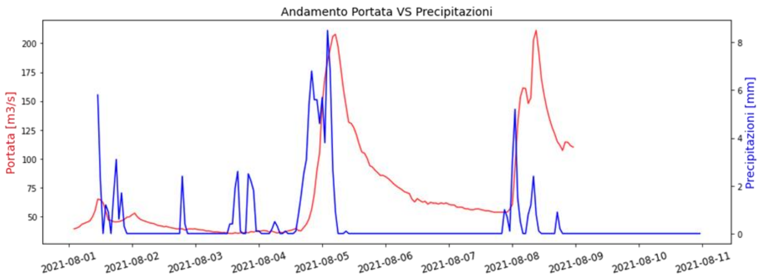
- Fortezza
- Gioveretto
- Rio Pusteria

Main features of the solution:

- Three different flow scenarios in the worst conditions of rain precipitation
- Hourly frequency, with a forecast of 27 hours for the execution.
- deep learning algorithms to simulate the behavior of the basin based on the weather forecast of the following hours on the whole surface of the hydrographic basin (3 precipitation scenarios)
- Historical flow data for the training are selected to be representative of flood waves.

Method

Available data

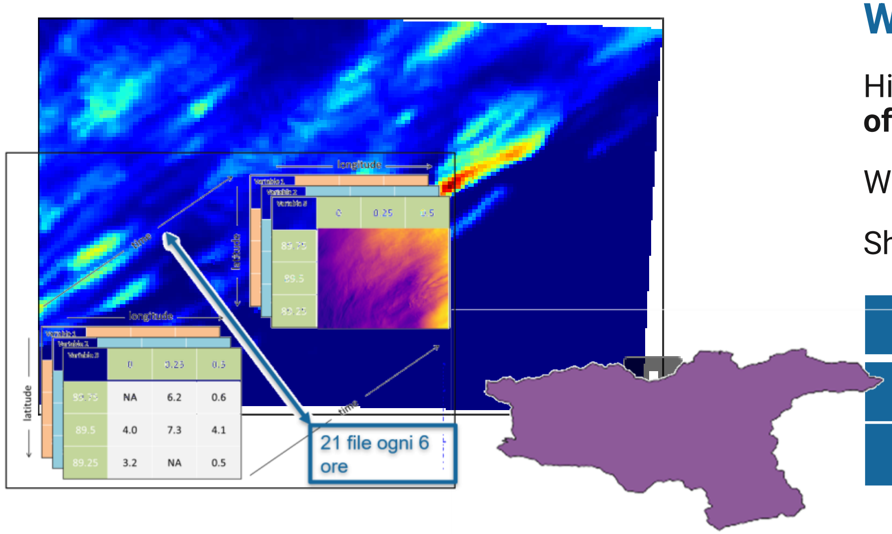


Historical flood waves an real precipitation for each basin

Real precipitation are used to design the weather forecast extraction pipeline.

Basin	Period	N. of available floods
Fortezza	08.2021	2
Gioveretto	08-10.2020	4
Rio Pusteria	08-09.2020	2

file:c2e_bozen_011.grb2 immagine:



Weather forecast and basin shape file

Historical weather forecast for training and validation to implement a model able **to manage the uncertainty of weather forecast**, real-time weather forecast for prediction.

Weather files are in a **grid** format and represent ensemble forecast (multiple scenarios for each hour).

Shape file is useful to select the area.

Format	Used for	N. scenarios	Hours of forecast
.grib	Training + Validation	21	120
.netCDF	Execution	11	36

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Method

Data preprocessing for the training

Ora	T-24	T-23	T-22	T-21	T-20	T-19	T-18	T-17	T-16	T-15	T-14	T-13	T-12	T-11	T-10	T-9
OUTPUT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
INPUT Cumulata pioggia	PIOGGIA STORICA -24	PIOGGIA STORICA -23	PIOGGIA STORICA -22	PIOGGIA STORICA -21	PIOGGIA STORICA -20	PIOGGIA STORICA -19	PIOGGIA STORICA -18	PIOGGIA STORICA -17	PIOGGIA STORICA -16	PIOGGIA STORICA -15	PIOGGIA STORICA -14	PIOGGIA STORICA -13	PIOGGIA STORICA -12	PIOGGIA STORICA -11	PIOGGIA STORICA -10	PIOGGIA STORICA -9
INPUT Portata	PORTATA REALE -24	PORTATA REALE -23	PORTATA REALE -22	PORTATA REALE -21	PORTATA REALE -20	PORTATA REALE -19	PORTATA REALE -18	PORTATA REALE -17	PORTATA REALE -16	PORTATA REALE -15	PORTATA REALE -14	PORTATA REALE -13	PORTATA REALE -12	PORTATA REALE -11	PORTATA REALE -10	PORTATA REALE -9

Ora	T-8	T-7	T-6	T-5	T-4	T-3	T-2	T-1	T-0	T+1	T+2	T+3	T+4	T+5	T+6	T+7
OUTPUT	-	-	-	-	-	-	-	-	**PREDIZIONE 0**	**PREDIZIONE 1**	**PREDIZIONE 2**	**PREDIZIONE 3**	**PREDIZIONE 4**	**PREDIZIONE 5**	**PREDIZIONE 6**	**PREDIZIONE 7**
INPUT Cumulata pioggia	PIOGGIA STORICA -8	PIOGGIA STORICA -7	PIOGGIA STORICA -6	PIOGGIA STORICA -5	PIOGGIA STORICA -4	PIOGGIA STORICA -3	PIOGGIA STORICA -2	PIOGGIA STORICA -1	PIOGGIA PREDETTA 0	PIOGGIA PREDETTA 1	PIOGGIA PREDETTA 2	PIOGGIA PREDETTA 3	PIOGGIA PREDETTA 4	PIOGGIA PREDETTA 5	PIOGGIA PREDETTA 6	PIOGGIA PREDETTA 7
INPUT Portata	PORTATA REALE -8	PORTATA REALE -7	PORTATA REALE -6	PORTATA REALE -5	PORTATA REALE -4	PORTATA REALE -3	PORTATA REALE -2	PORTATA REALE -1	PORTATA REALE -0	PREDIZIONE 0	PREDIZIONE 1	PREDIZIONE 2	PREDIZIONE 3	PREDIZIONE 4	PREDIZIONE 5	PREDIZIONE 6

Ora	T+8	T+9	T+10	T+11	T+12	T+13	T+14	T+15	T+16	T+17	T+18	T+19	T+20	T+21	T+22	T+23	T+24
OUTPUT	**PREDIZIONE 8**	**PREDIZIONE 9**	**PREDIZIONE 10**	**PREDIZIONE 11**	**PREDIZIONE 12**	**PREDIZIONE 13**	**PREDIZIONE 14**	**PREDIZIONE 15**	**PREDIZIONE 16**	**PREDIZIONE 17**	**PREDIZIONE 18**	**PREDIZIONE 19**	**PREDIZIONE 20**	**PREDIZIONE 21**	**PREDIZIONE 22**	**PREDIZIONE 23**	**PREDIZIONE 24**
INPUT Cumulata pioggia	PIOGGIA PREDETTA 8	PIOGGIA PREDETTA 9	PIOGGIA PREDETTA 10	PIOGGIA PREDETTA 11	PIOGGIA PREDETTA 12	PIOGGIA PREDETTA 13	PIOGGIA PREDETTA 14	PIOGGIA PREDETTA 15	PIOGGIA PREDETTA 16	PIOGGIA PREDETTA 17	PIOGGIA PREDETTA 18	PIOGGIA PREDETTA 19	PIOGGIA PREDETTA 20	PIOGGIA PREDETTA 21	PIOGGIA PREDETTA 22	PIOGGIA PREDETTA 23	PIOGGIA PREDETTA 24
INPUT Portata	PREDIZIONE 7	PREDIZIONE 8	PREDIZIONE 9	PREDIZIONE 10	PREDIZIONE 11	PREDIZIONE 12	PREDIZIONE 13	PREDIZIONE 14	PREDIZIONE 15	PREDIZIONE 16	PREDIZIONE 17	PREDIZIONE 18	PREDIZIONE 19	PREDIZIONE 20	PREDIZIONE 21	PREDIZIONE 22	PREDIZIONE 23

The **training dataset** is structured for each flood wave by **shifting** both the historical **flood data** and the **precipitation time-series** of **23 hours**, and including the **cumulative sum of precipitation volume for the last 24 hours**.

Each flood wave is treated individually in order to shift on the right axis without overlapping different periods, and then merged based on the basin.

Flood waves selection

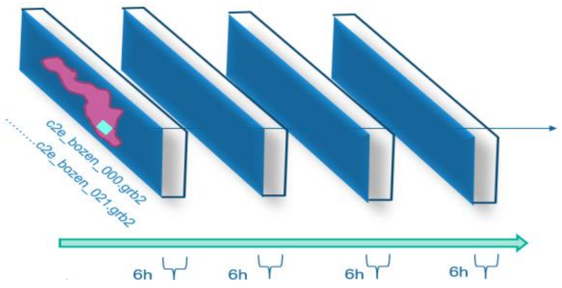
N-1 flood waves are used for the training, the last flood wave is kept for validation.

Basin	Training period	N. of floods in the period
Fortezza	2021-08-01 02:00:00 - 2021-08-06 22:00:00	1
Gioveretto	2020-08-28 22:00:00 - 2020-10-06 00:00:00	3
Rio Pusteria	2020-08-27 11:00:00 - 2020-09-02 00:00:00	1

Weather forecast exctraction

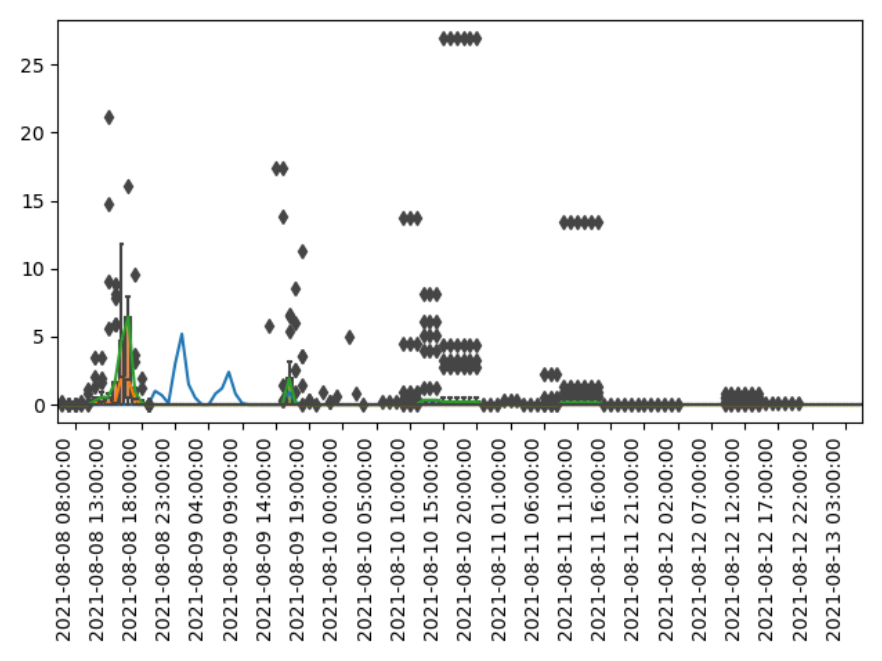
From grid to timeseries:

1. For each forecast the first 6 hours are selected and merged with the following forecast.
2. From the entire data structure of merged forecast are extracted 5 latitude-longitude points representing the basin area
3. For each hour and each point, the 21 values of precipitation are used to extract the **third quartile** of the distribution, obtaining 5 different time series of probable precipitation per point



Method

Data preprocessing for the training - **Why the third quartile?**



Comparing real precipitation data during historical flood waves and historical weather forecast, the **third quartile best represents high intensity events**.

Flood waves selection

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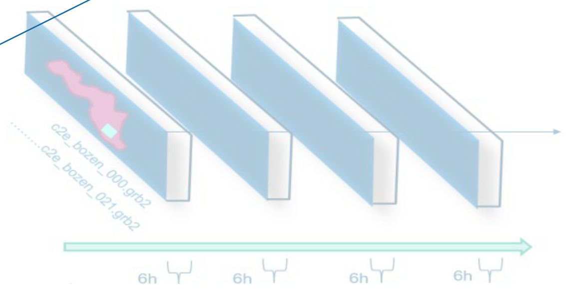


Method

Model implementation and testing

The model

Feedforward neural network with a forced recursion in the execution loop.

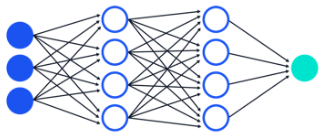
- 2 layers
  - 150 neurons on the first hidden layer
  - 185 on the second hidden layer
- Stochastic gradient descent solver
- Hyperbolic tangent as activation function

Training and testing

Training: 66% of observation extracted in a random way from the training dataset with the third quartile of each map point and the historical flood waves.

Test: 33% is used to test the model performances and avoid overfitting. On the historical dataset, without the execution loop which guarantees recursion and is better detailed in the following paragraph, the test metrics are aligned with the expectation.

47 VARIABILI:
- Cumulata Pioggia Totale shiftata
- Portata Totale shiftata



1 VARIABILE:
- Portata Totale

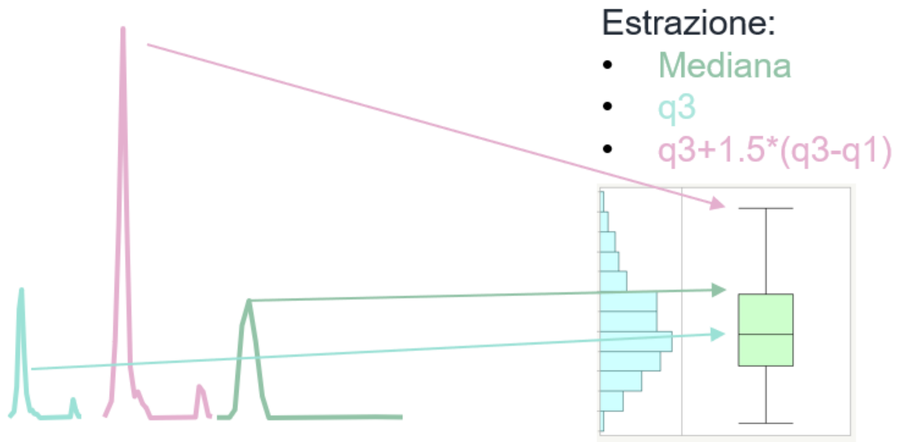
Basin	R2 test	MSE test	MAPE test
Fortezza	99%	21.1	1.2%
Gioveretto	97%	22.2	0.9%
Rio Pusteria	99%	23.4	3.2%

Method

Validation

Exctracting 3 scenarios

From the 21 scenarios, median, third quartile and whisker are exctracted to represent the low intensity, most probable and high intensity scenario.



FLOW FORECAST FOR: 08/06 12:00 + 120 HOURS

FLOW FORECAST FOR: 08/07 06:00 + 120 HOURS

FLOW FORECAST FOR: 08/06 18:00 + 120 HOURS

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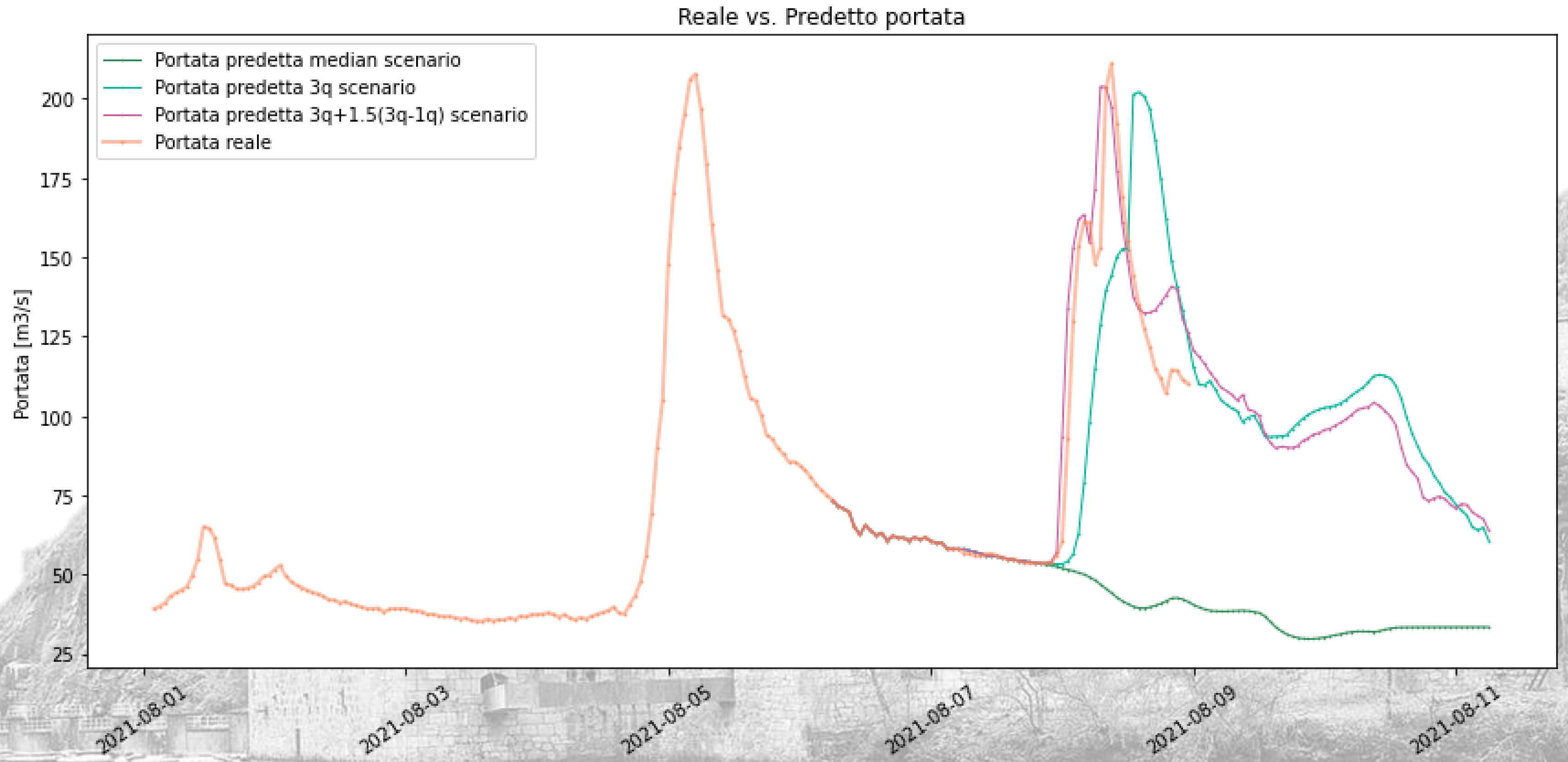
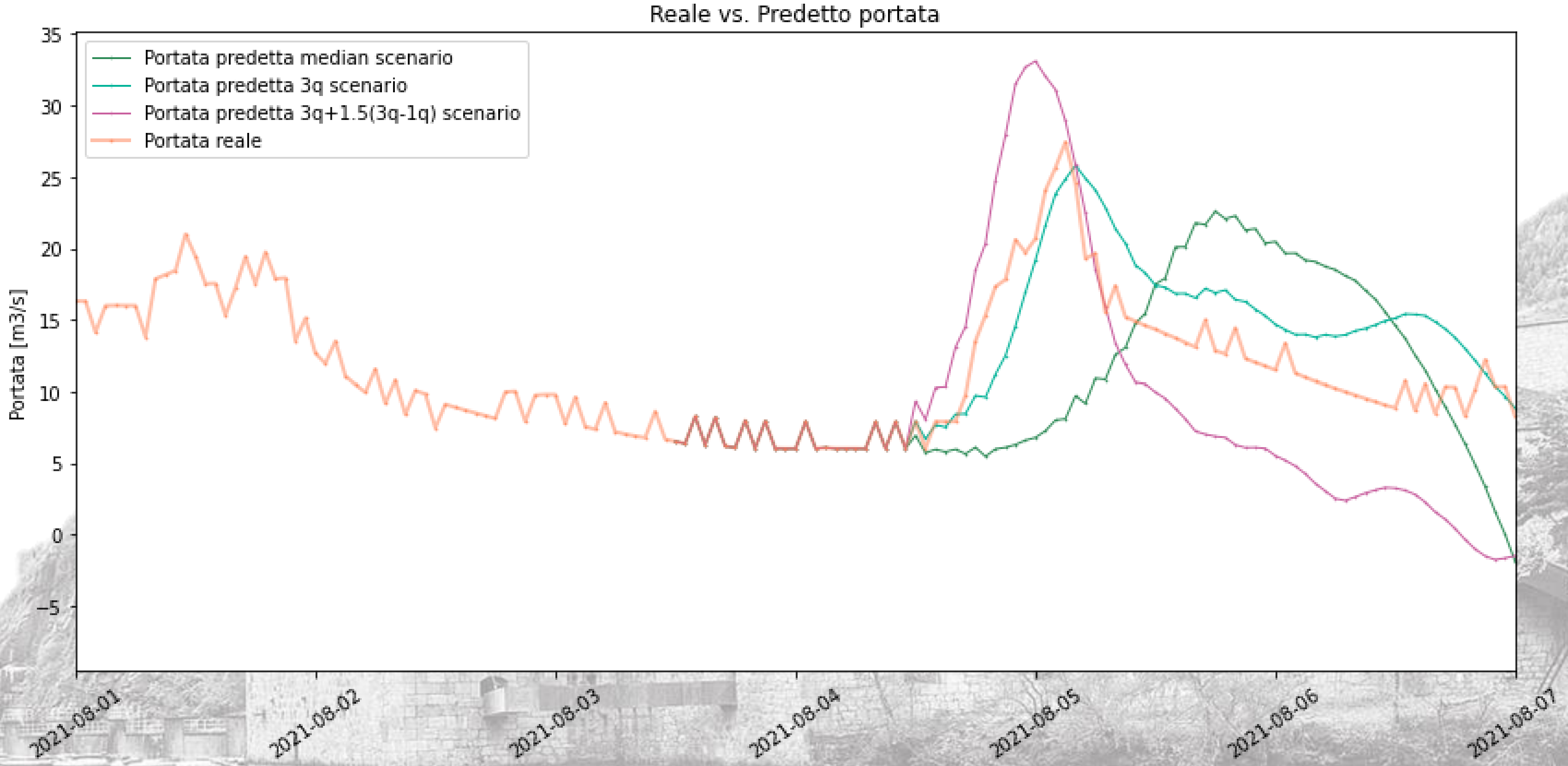
Fortezza



Reale vs. Predetto portata
Portata predetta median scenario
Portata predetta 3q scenario
Portata predetta 3q+1.5(3q-1q) scenario
Portata reale
Portata [m3/s]
200
175
150
125
100
75
50
25
2021-08-01
2021-08-03
2021-08-05
2021-08-07
2021-08-09
2021-08-11

Gioveretto



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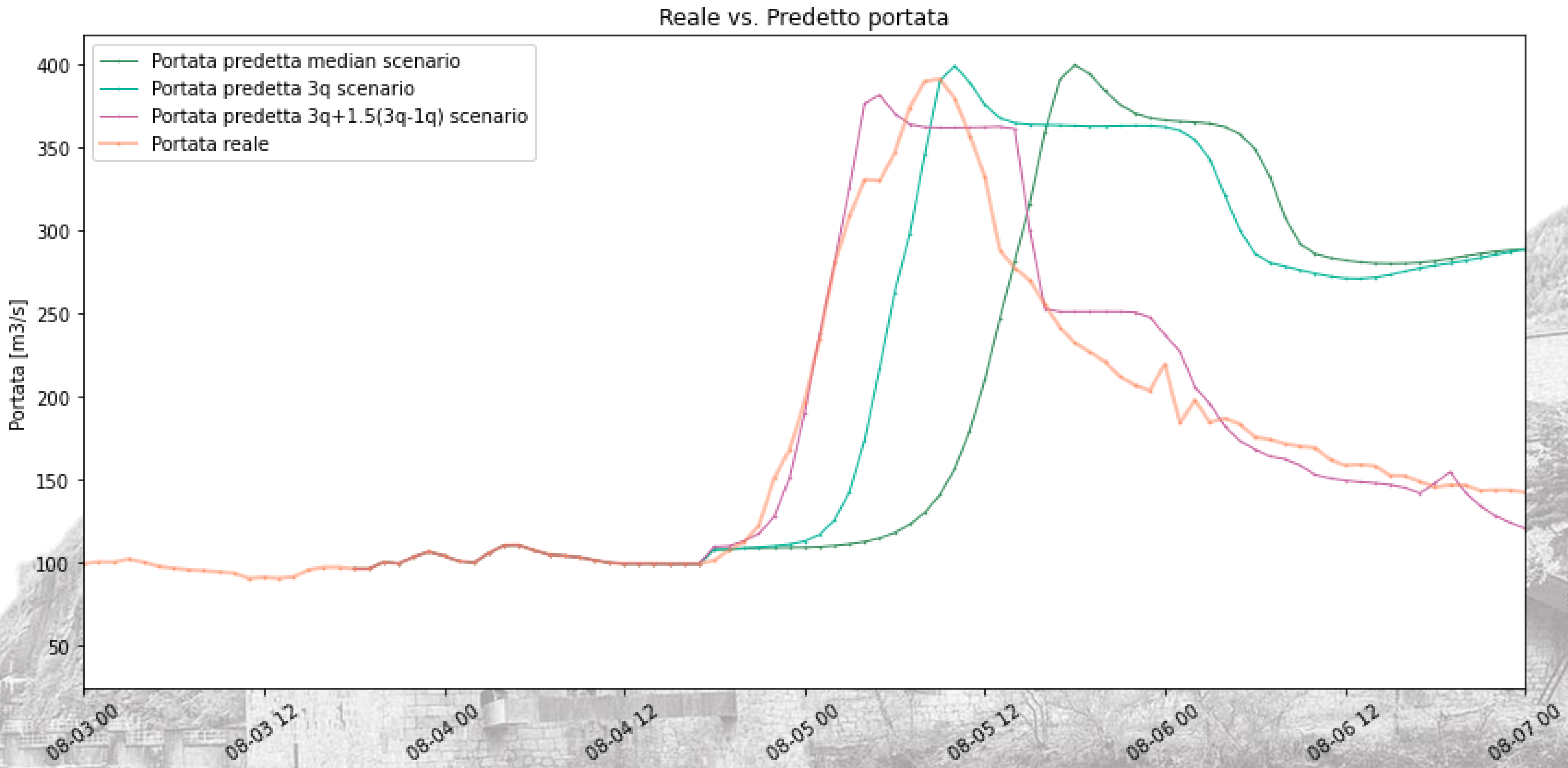
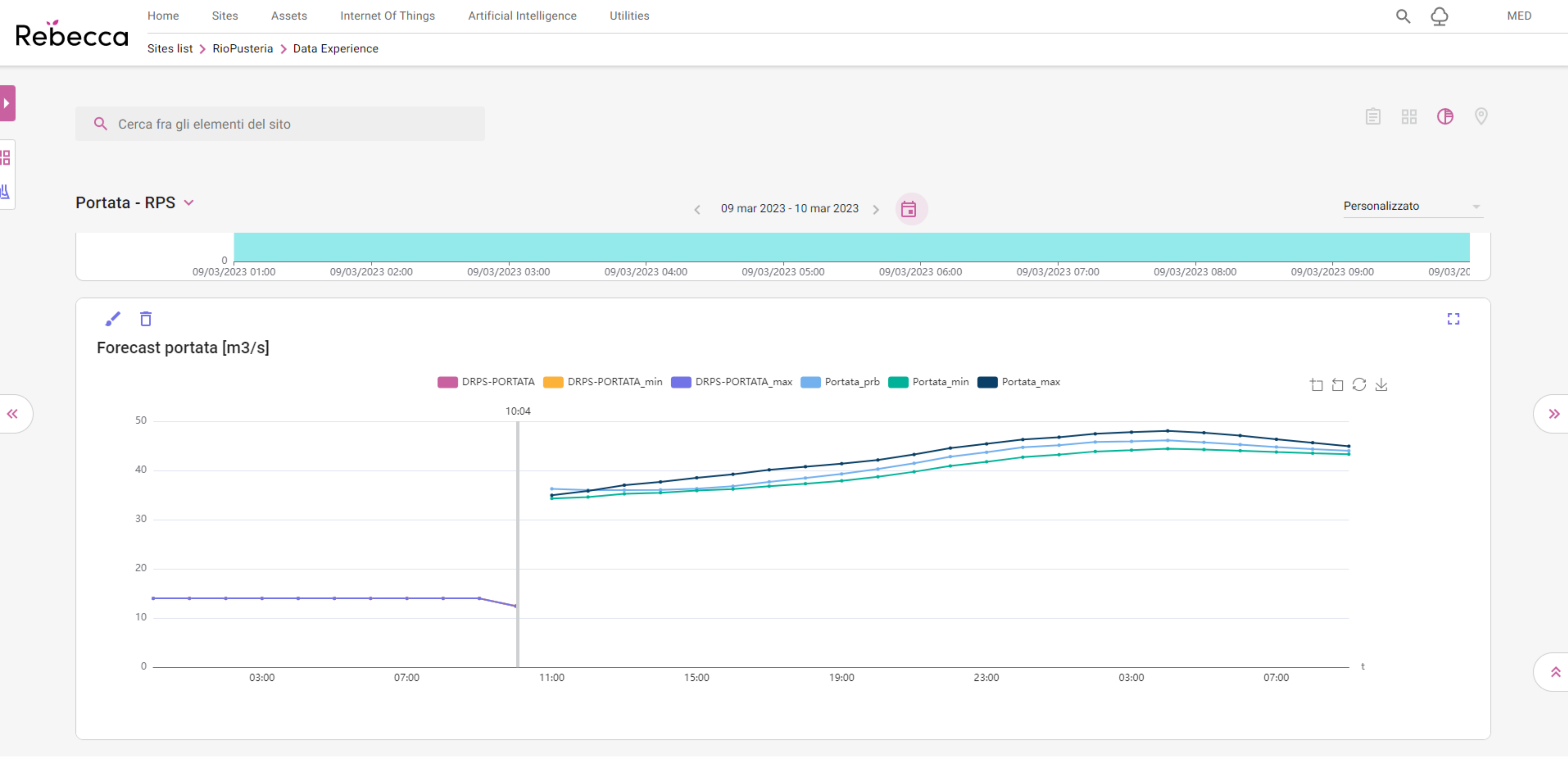
Rio Pusteria



Method

Model operation

- The recursion loop runs only 30 times, which is the period of guaranteed availability of weather prediction (36 hours of forecast – 6 hours of forecast update periodicity). The results are shown for the following **27 hours**, accordingly to the operative procedure of the study.
- The model operates on **cloud** and in a **proprietary platform**. The architecture includes **two different connectors** to collect **real-time flow data** from the **SCADA** and **weather forecast** provided in a specific directory **each 6 hours**.
- The model **runs hourly** and for each hour prediction it uses the last weather forecast (updated 1 to 5 hours before) and the last flow value (updated hourly).
- The flow prediction is sent to **a hydroelectric plant simulator** which tests different **plant conduction opening and closing of bulkheads in order to maximize the exploitation of the flood wave minimizing risks and damages for the basin and the plant**.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Portata - RPS
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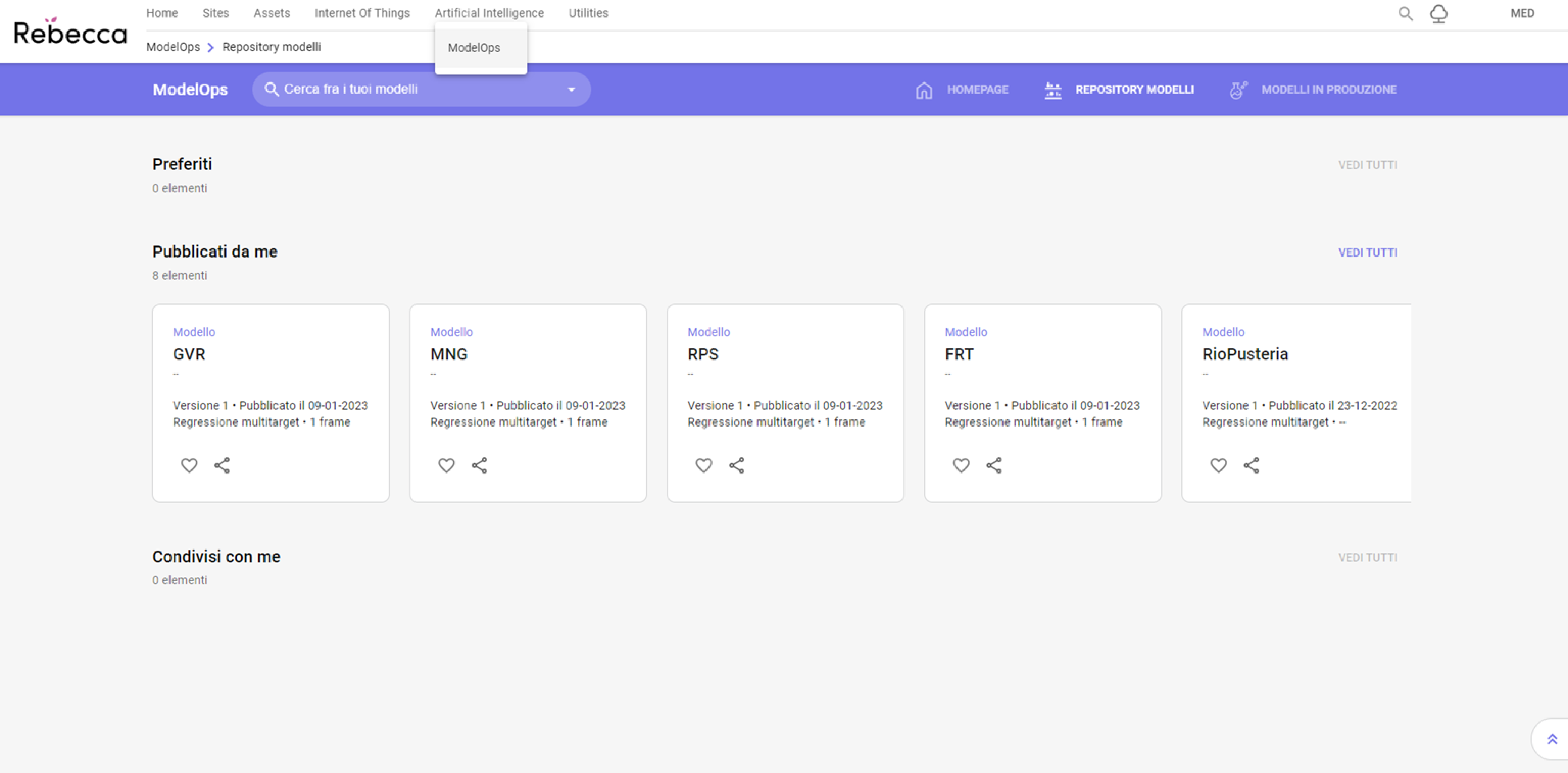
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Conclusions

The **main achievements** of the study are

- the proven possibility to model a **generic basin** starting **solely from weather forecast and historical flow and flood waves**
- the **increased prediction performance** in **real-time** which is able to **manage the intrinsic imprecision of weather forecast**, thanks to the data preprocessing, the selection of a deep feedforward neural network as core algorithm, and the use of historical forecast during the training.

The study opens to new additional researches in the field, such as **the use of convolutional neural networks to avoid time-series extraction from the weather forecast grid**, the **simulation of base flow in addiction to peak flow during flood waves**, or **the use of optimization algorithms to increase the precision of the hydroelectric plant management.**

The intuition for the study and related funding has been provided by Alperia Greenpower after a study on the impact and frequency of recent flood waves in the basins under their control. The implementation work on the predictive model for flood wave has been completed by MIPU Energy Data industrial AI team, and industrialized on Rebecca platform.
Weather forecast is provided by MeteoSwiss.

Thank you

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