EPFL

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Zentrum für alpine Umweltforschung
Research center on alpine environment

Development of a Forecasting Tool for Groundwater Levels in Valais Using Advanced Computational Techniques

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Design Project in cooperation with
CREALP, Research Center on Alpine Environment

duration of project: March-July 2021

Environmental Sciences and Engineering

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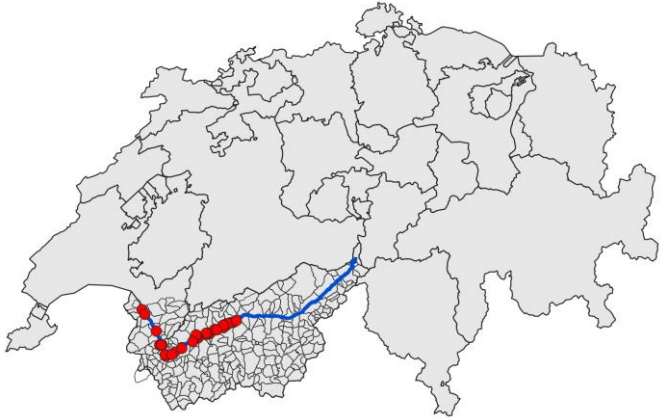
Groundwater Prediction could be an integral part of Risk Management in Valais



Groundwater is the main water stock in Switzerland.

The canton of Valais is facing reccuring...

- flooding (e.g. of agricultural fields)
- threats by rising water table on polluted sites

Prevention & sustainability

- Need for detection of early-stage changes in groundwater table as part of the risk management
- Current monitoring network of 320 stations
- Integrate **forecasting of groundwater levels** to anticipate events

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Two objectives are to be adressed

Goal 1

Improve the understanding of how groundwater levels are behaving in Valais

Goal 2

Develop a groundwater level forecasting model

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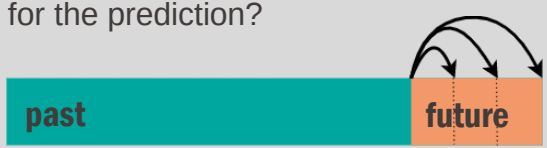
2-step Strategy towards a forecasting tool

1 Exploratory Data Analysis (EDA)

- Determine cross-correlations between groundwater levels and external variables like temperature and precipitation
- Auto-correlation
- Fourier Transform to find frequencies of the groundwater level signal
- Clustering of different types of behaviors

2 Machine Learning Model (ML)

- EDA tells us which elements are important for the forecasting
- Forecasting model based on: Random Forest Regressor
- Evaluate the prediction quality
- Which information is most valuable for the prediction? Same as found in EDA?



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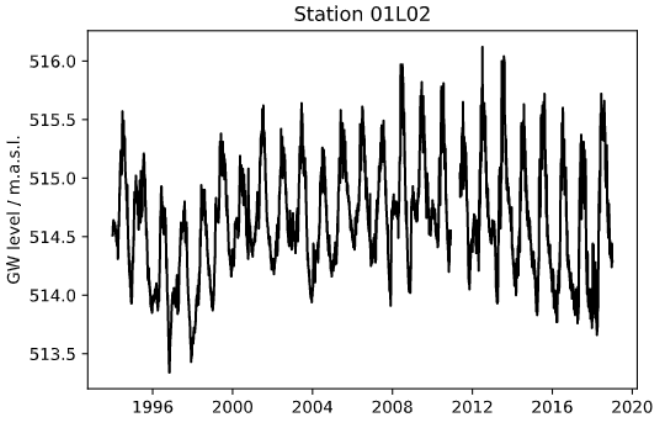
Elements impacting the Groundwater Level in Valais

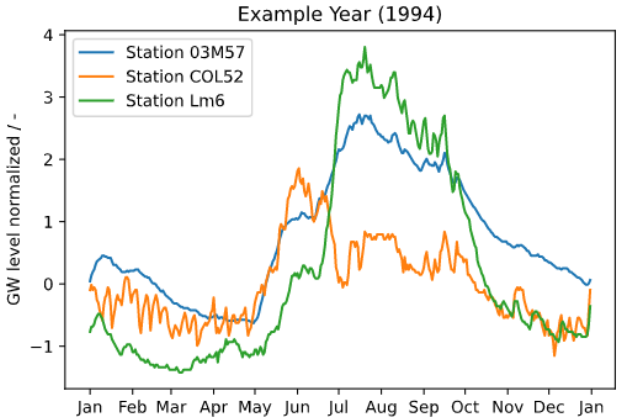
- Rhône discharge (pressure or mass exchange)
- Air temperature
- Rainwater
- Meltwater from snow & ice
- Topography
- Geology & soil
- Water withdrawal
- Land use, vegetation
- ...

Yearly patterns according to hydrological regime and seasonality.

Behavior varies between stations.

→ We will take a look at **25 years of data**.





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Data has been aggregated beforehand

Spatialized data over the canton is aggregated to 1 value per station.

VAP

(volumetric available precipitation)

- m^3/day
- Represents local available water from precipitation
- Physical elements:
  - rain
  - snowmelt delay
  - evapotranspiration

Q_{int}

(interpolated discharge)

- m^3/day
- Represents Rhône discharge at the height of the station
- Physical elements:
  - glaciers
  - snowmelt
  - precipitation

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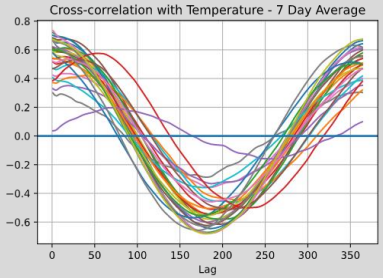
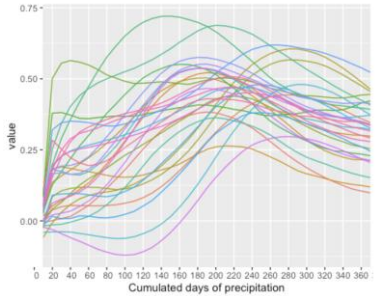
External variables are impacting Groundwater Levels on short & long scale

Air temperature



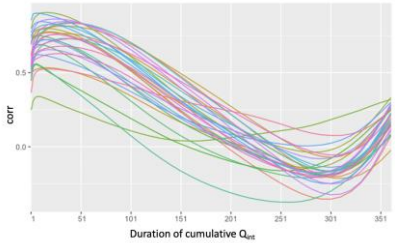
- Correlation up to 100 days
- Gives information about underlying seasons & current weather.

VAP (volumetric available precipitation)



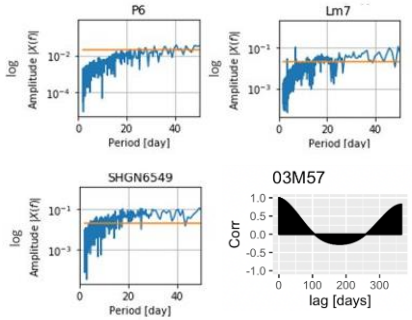
- Three influences:
  - Last month (20 days): low water period
  - Last 6 months: stock and release of snow
  - Annual seasonality (270 days)

Q_{int} (interpolated discharge)



- Two patterns:
  - Direct reaction (5-10 days)
  - Short-term reaction (20+ days)

Past Groundwater Level



- 3 patterns from Fourier Transform: variability either noisy/smooth/ in between
- Autocorrelation of groundwater levels up to 100 days

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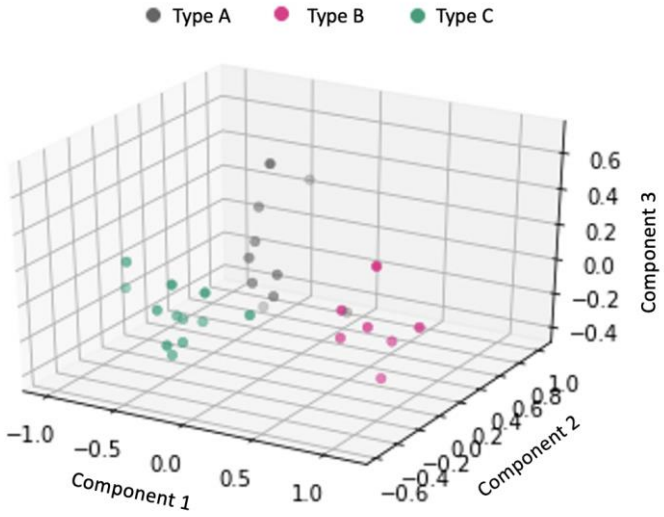
Station behaviors can be clustered in 3 types

Type A	Type B	Type C
04S70	03M57	01L02
09M06	07E06	04I52
10E02	07G06	05X55
COL8	Lm5	08E6
Lm6	Lm7	COL52
Lm9b	Lm8	COL53
SHGN6543	RN14	Lm3
SHGN6545		Lm4
SHGN6546		P117
SHGN6549		P6
		P67
		S167



- Clustering using **K-means algorithm**: Unsupervised Machine Learning method which finds the number of groups autonomously
- Input: correlation values found in EDA

→ **3 clusters** were identified

→ **What do they correspond to?**

Analysis of the Station Types

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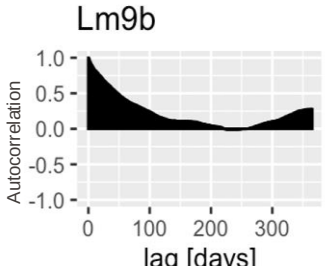
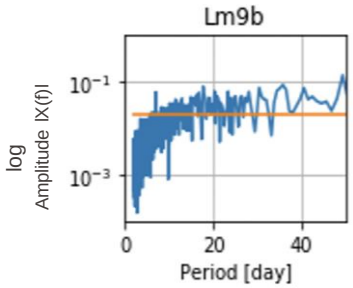
Type A

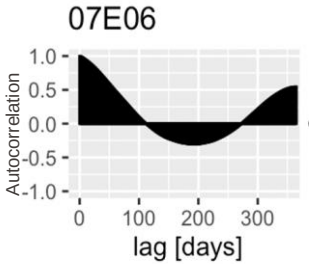
- Short-term variations are important
- Linked to precipitation events

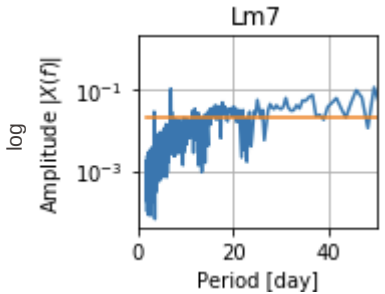




Type B

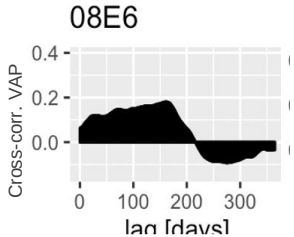
- Cyclic annual patterns are the most important
- Important link to Rhône's discharge

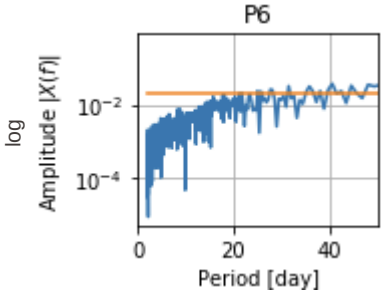




Type C

- Cyclic annual patterns are important
- Specificities of the last months as well
- High inter-type variability





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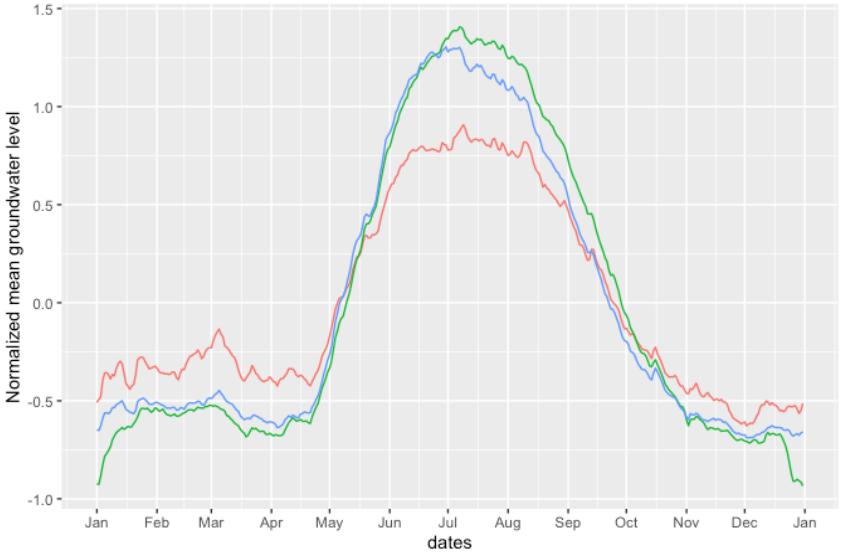
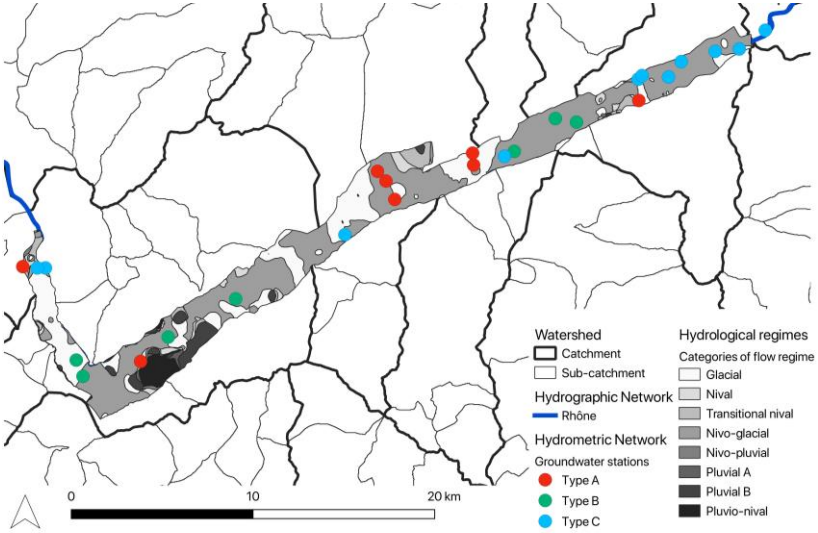
Station Types differ mainly by hydrological regime





Goal 1

We identified some factors and links influencing groundwater in Valais.

Groundwater Levels should be predicted every 7 days

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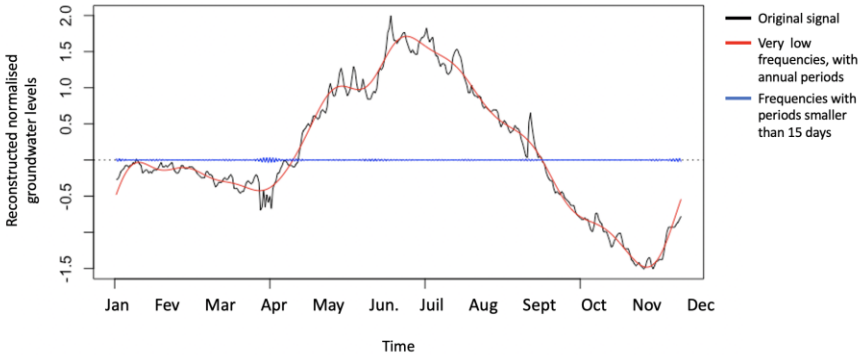
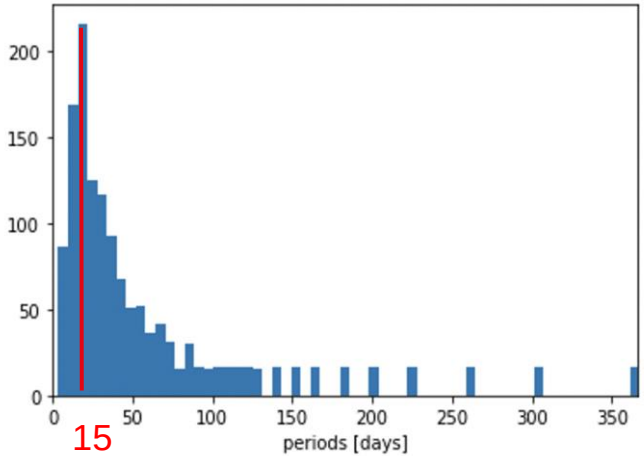
Nyquist theorem

A signal may be uniquely and precisely reconstructed with a sampling rate that is equal to, or greater than, twice the highest significant frequency in the signal.

Fourier Transform analysis

1. Forecast resolution should be of 7 days for reconstructing the groundwater level variations (Nyquist theorem).
2. Samples of past groundwater levels should be taken more often than every 7 days.





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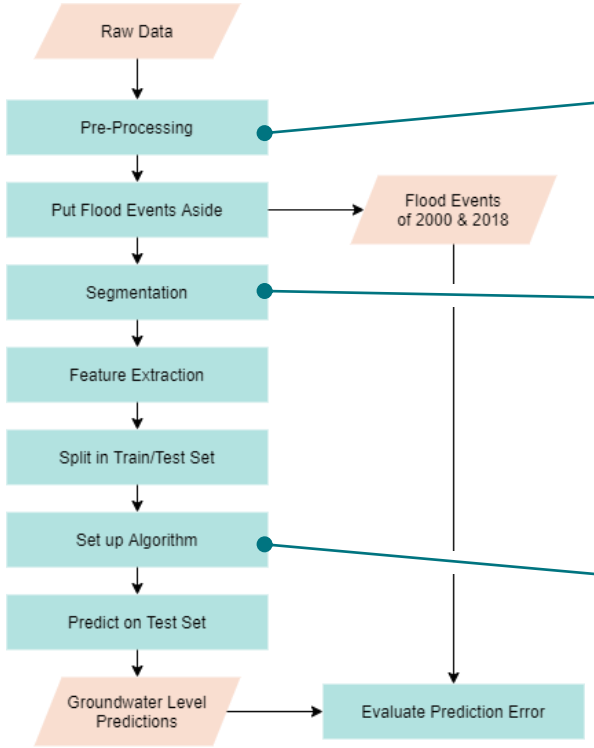
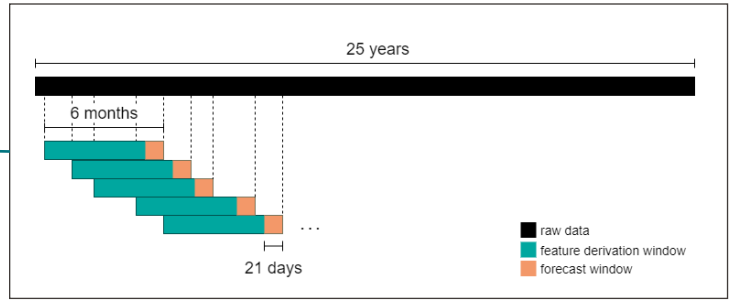
Building a Machine Learning model to predict Groundwater Levels



normalization since stations are on different elevation



Random Forest Regressor

+ allows certain insight
+ robust (ensemble learning)
+ allows use of different feature types

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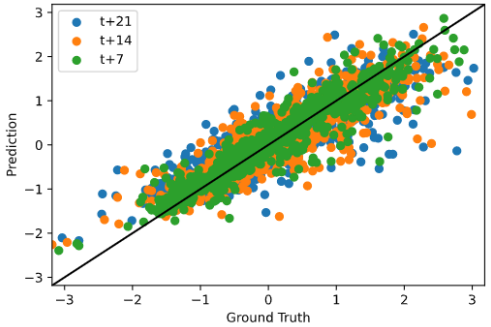
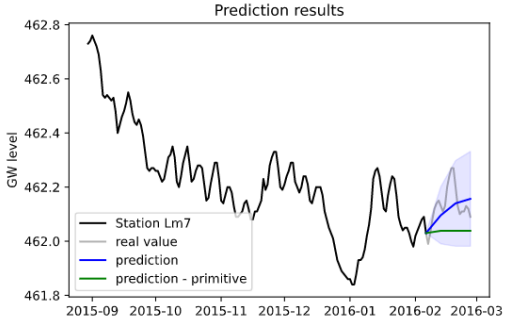
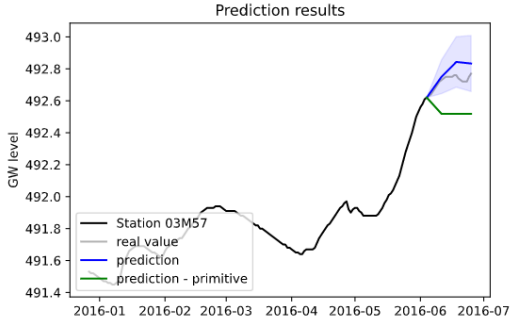
A simple model yields promising results for the forecasting task







	Overall		Type A	Type B	Type C
R^2 score	**0.80**		**0.70**	0.84	0.82
	RMSE	Maximum error	RMSE	RMSE	RMSE
t+7 days	0.11 m	0.68 m	0.10 m	0.10 m	0.11 m
t+14 days	0.16 m	1.29 m	0.16 m	0.15 m	0.16 m
t+21 days	0.18 m	0.91 m	0.17 m	0.15 m	0.19 m

RMSE: Root Mean Squared Error; R^2 score: coefficient of determination

- Large variance in the performance between stations (R^2 from -2.86 to 0.94)
- Less precise on station type A
- Better than primitive model (R^2: 0.72)

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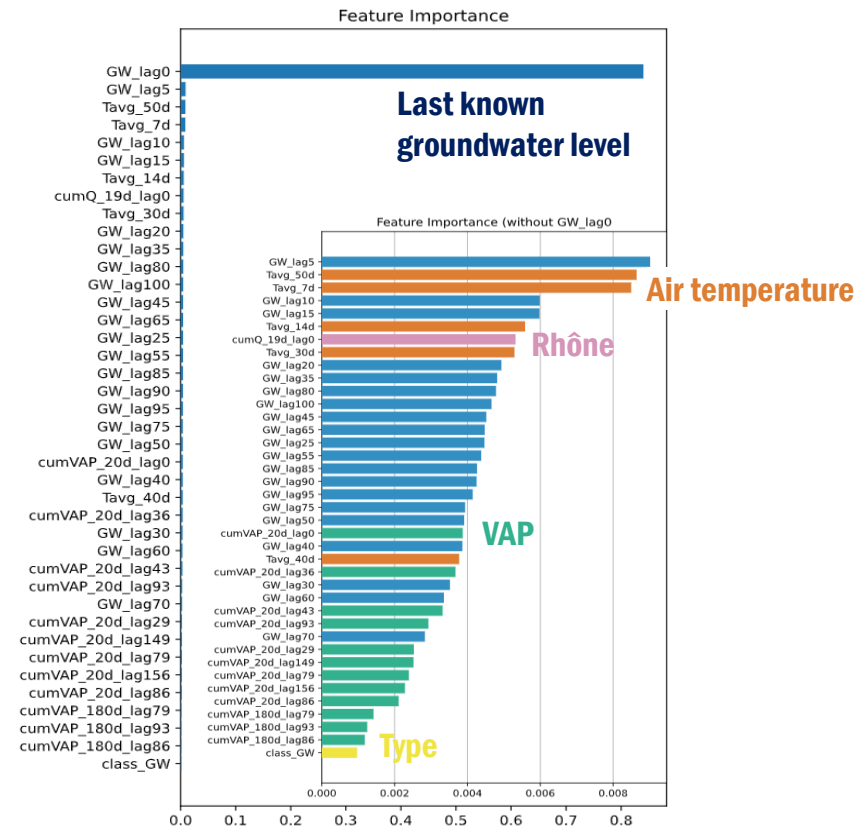
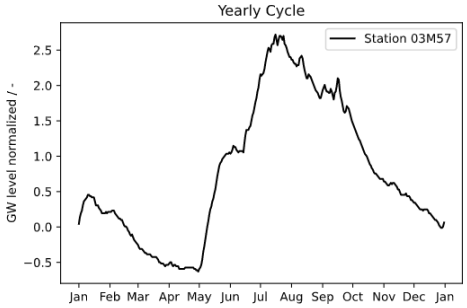
Various possibilities to improve the forecasting in the future





Our propositions

1. Apply a **high-pass filter** to remove the annual pattern.
2. Apply a **low-pass filter** to focus on trend rather than uncapturable short-term variations.
3. Use **forecasting features** (meteoSwiss, Crealp) since groundwater levels showed dependancy on recent conditions.
4. Build one **specialized model per type** of station.

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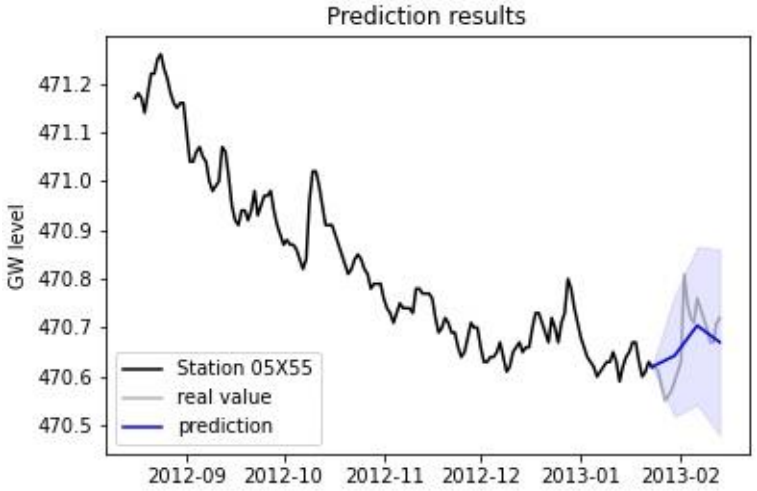
A first forecasting model is established



Goal 2

Our model can serve as a first forecasting tool of groundwater levels in Valais, allowing further improvement in the future.

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Further work focuses on operational implementation

Planned modifications

- identification of **reference stations** in susceptible areas
- stations in proximity with similar behavior are used to aid the model

Online platform for Groundwater Forecast in Valais is under development