Hydrological data assimilation using the Particle Filter in a semi-distributed model MORDOR-SD

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Overview

A- Context of study

B- Sensitivity of Summer streamflow forecast to snow quantity

C- How does streamflow assimilation in winter improve snow stock estimates in end of winter?

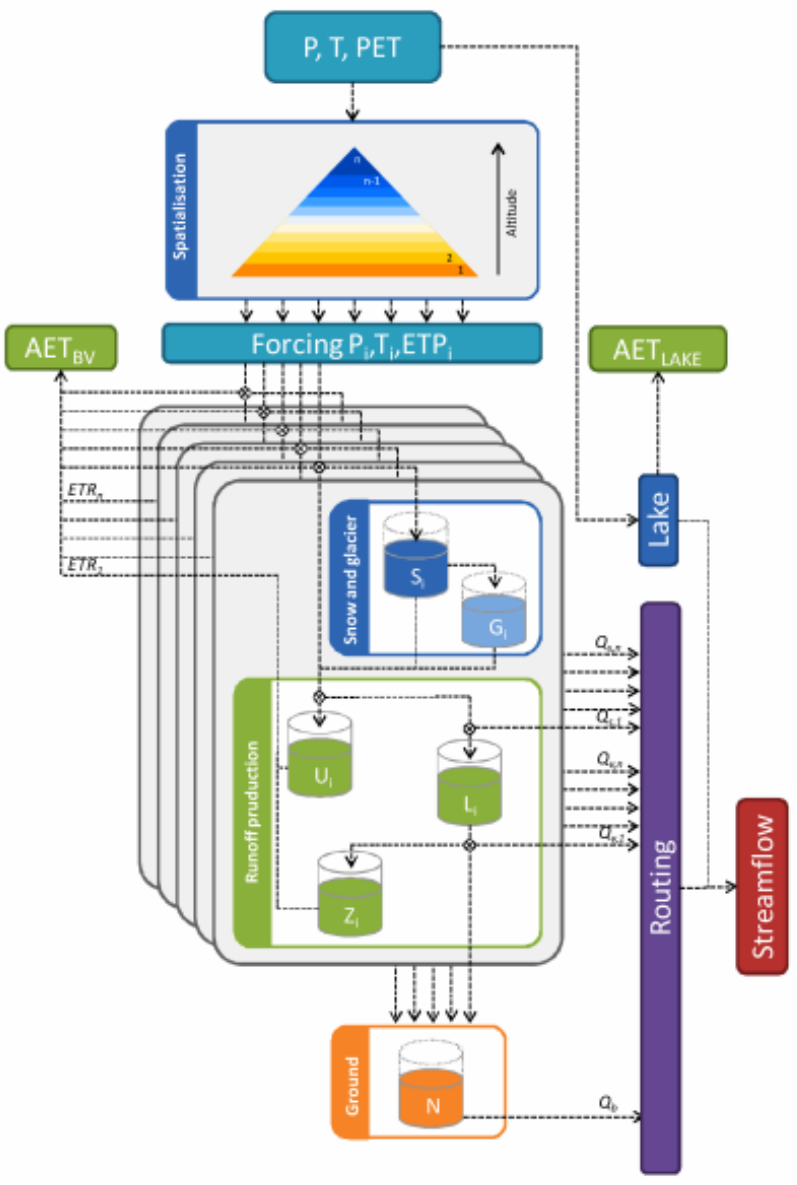
D- Is the snow stock estimate improved by assimilating NRC?

E- Conclusion

Context of study

- Hydraulic energy is dependent on available water reserves. To generate energy in the most efficient way, it is necessary for the french electricity production agency (E.D.F.) teams to predict the water reserves supplying the hydro turbines.

- Numerical modelisation is used to predict the water reserves}. In ordor to help to forecast these water reserves, the **MORDOR-SD** (T. Mathevet, 2005)



Context of study

Problematic

- The snow reserves made during the winter strongly impact the flow in the spring and summer.
- At the end of the winter period, this stock of snow melts and turns into liquid and feeds the water flow.
- it is difficult to have a good estimate of the available snow stock.
- The uncertainty about this initial snow stock in the model will have an impact on the estimation of the water flow at the outlet.
- It is therefore essential to invest in reducing the uncertainty of the initial snow stock.

→ To assess the benefits of assimilating in situ observations into the forecast of water flow at the outlet of this reservoir mode

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Sensitivity of Summer streamflow forecast to snow quantity

The sensitivity of the model to its input parameters.

Sobol index

The Sobol index is commonly used to measure the sensitivity of a model to these inputs data. It is based on the decomposition of the variance of the model, and seeks to measure the variance due to each input separately. The higher this index is, the more the input parameter considered will have a strong influence on the model

- **Sobol index Saltelli version (2002)** :

  - Base: 2 Monte Carlo A and B samples, size N
  - Simulations: on N(K+2) combinations of factors calculated from A and B
  - Estimation of indices by vector calculation evaluation of precision by repetition

Monte-Carlo

$$A = \begin{pmatrix} x_{A,1;1} & \cdots & x_{A,1;K} \\ \cdots & \cdots & \cdots \\ x_{A,N;1} & \cdots & x_{A,N;K} \end{pmatrix}$$

Monte-Carlo

$$B = \begin{pmatrix} x_{B,1;1} & \cdots & x_{B,1;K} \\ \cdots & \cdots & \cdots \\ x_{B,N;1} & \cdots & x_{B,N;K} \end{pmatrix}$$

Combinations

$$\rightarrow C_i = \begin{pmatrix} x_{A,1;1} & \cdots & x_{B,1;i} & \cdots & x_{A,1;K} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{A,N;1} & \cdots & x_{B,N;i} & \cdots & x_{A,N;K} \end{pmatrix}$$

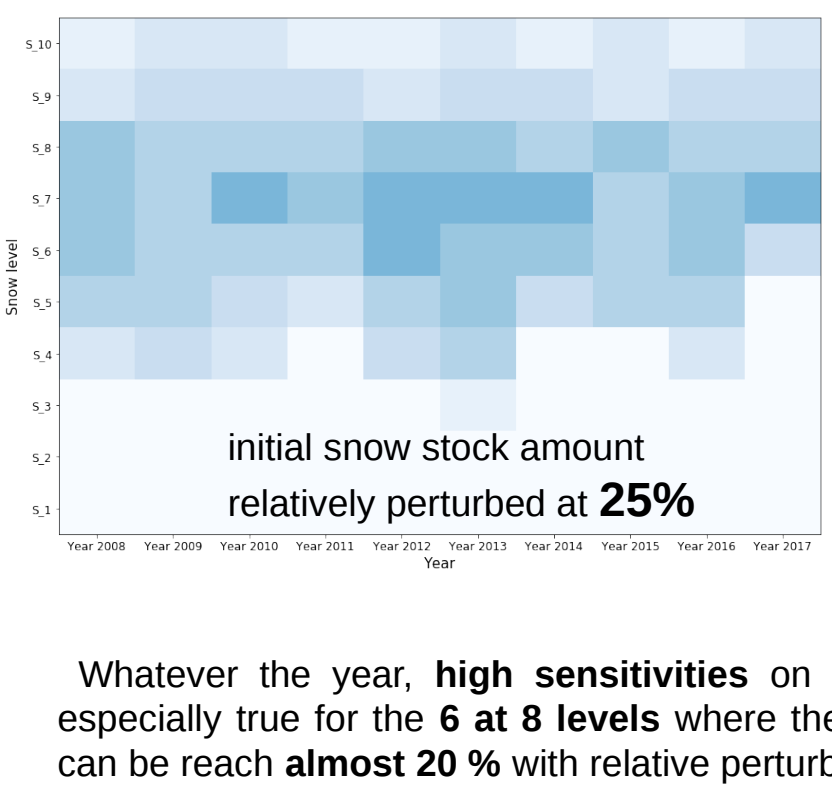
For i = 1, …, k

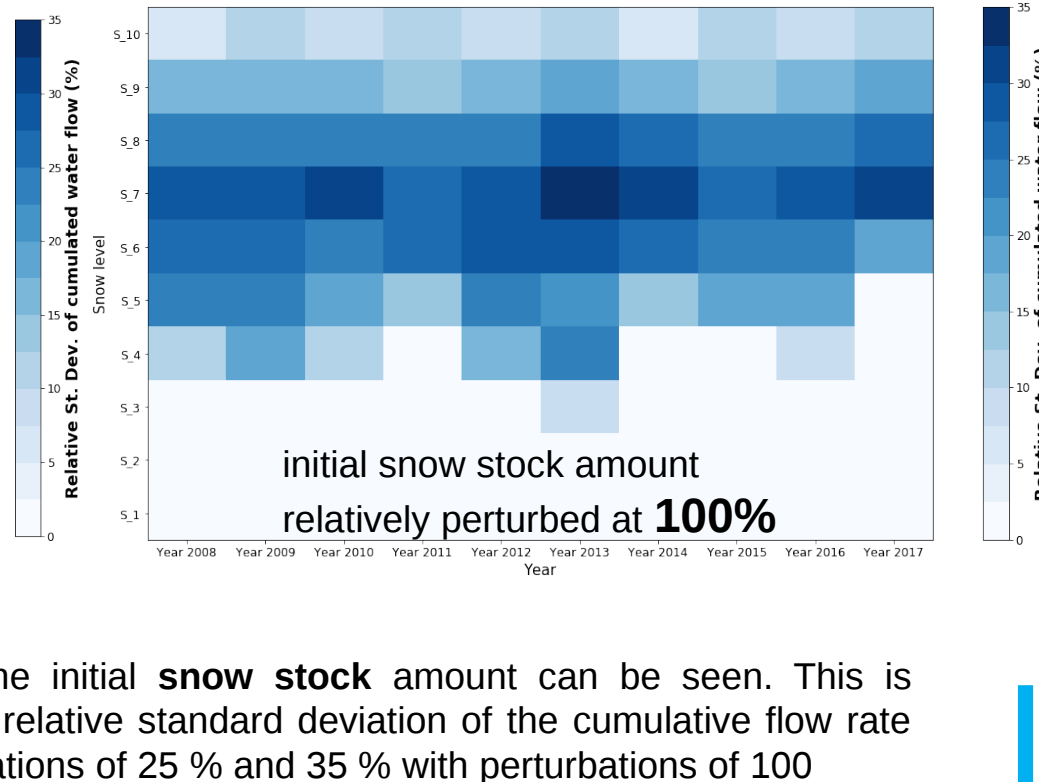
N×(2+K) simulation scenarios :

Sensitivity of Summer streamflow forecast to snow quantity

The sensitivity of the model to its input parameters.

Relative difference of the **standard deviation of the cumulative flow rate** obtained with a initial **snow stock amount** relatively **perturbed at 25 % and 100%,** as function of the snow stock amount estimated at **each model level** and as function of the year of simulation. Obtained on the watershed feeding the dam of the Coche, Isère, France).





Whatever the year, **high sensitivities** on the initial **snow stock** amount can be seen. This is especially true for the **6 at 8 levels** where the relative standard deviation of the cumulative flow rate can be reach **almost 20 %** with relative perturbations of 25 % and 35 % with perturbations of 100

How does streamflow assimilation in winter improve snow stock estimates in end of winter

Particle Filter

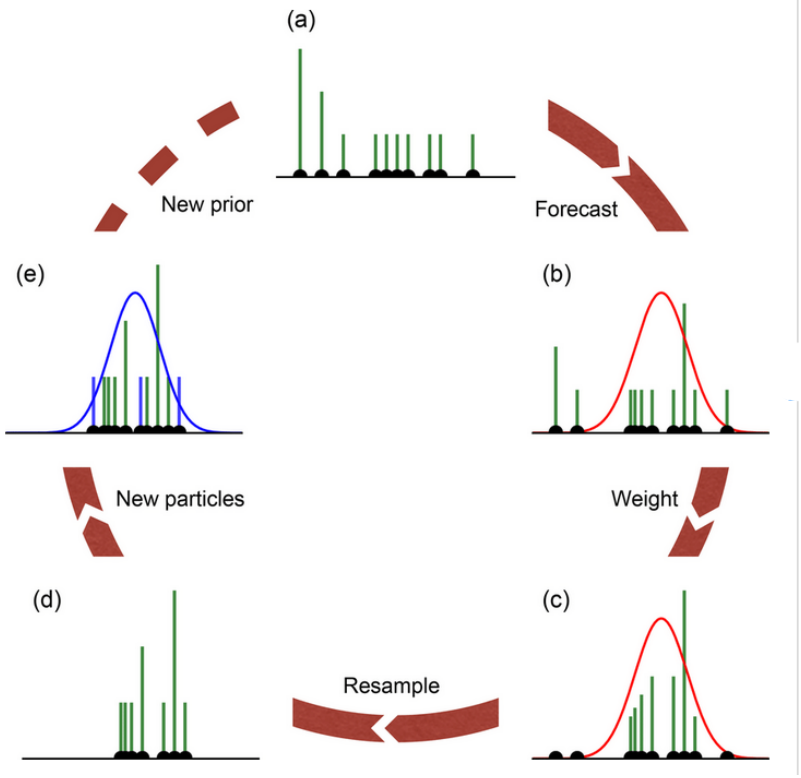


Illustration of the particle filter with

Kitagawa resampling (Kitagawa, 1996)

(a) The prior represented through the ensemble.

(b) The ensemble is propagated to the next observation (depicted as Gaussian distribution; red curve).

(c) The particles are weighted according to the observation (RMSE calculation).

(d) The universal resampling drops particles with low weight (three in this example).

(e) The new particles are duplicated from the full covariance of the ensemble.

Since new particles with weights are added to the ensemble, it is necessary to normalize the weights to 1 again. This results in the posterior, which is the prior for the next assimilation cycle.

How does streamflow assimilation in winter improve snow stock estimates in end of winter

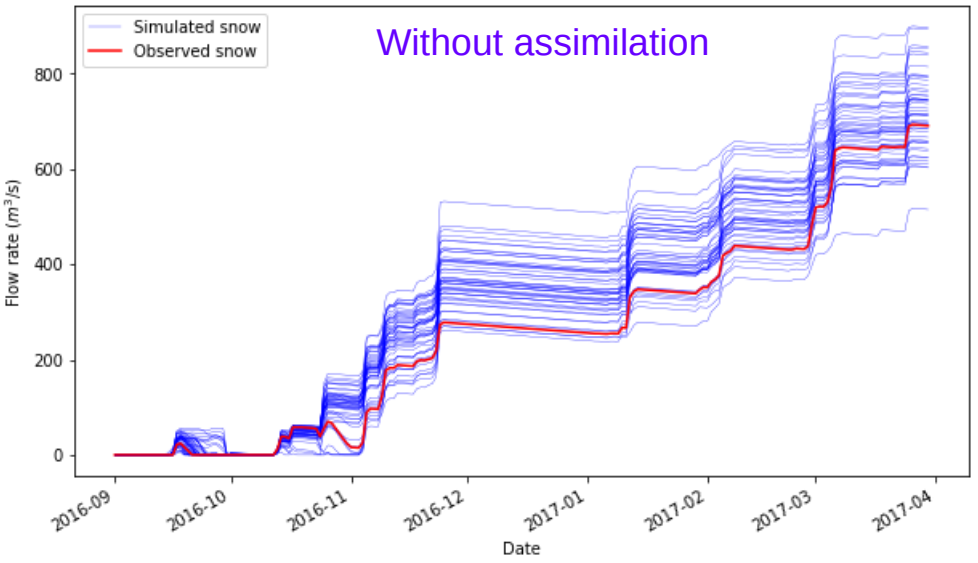
Assimilation of Q experiment

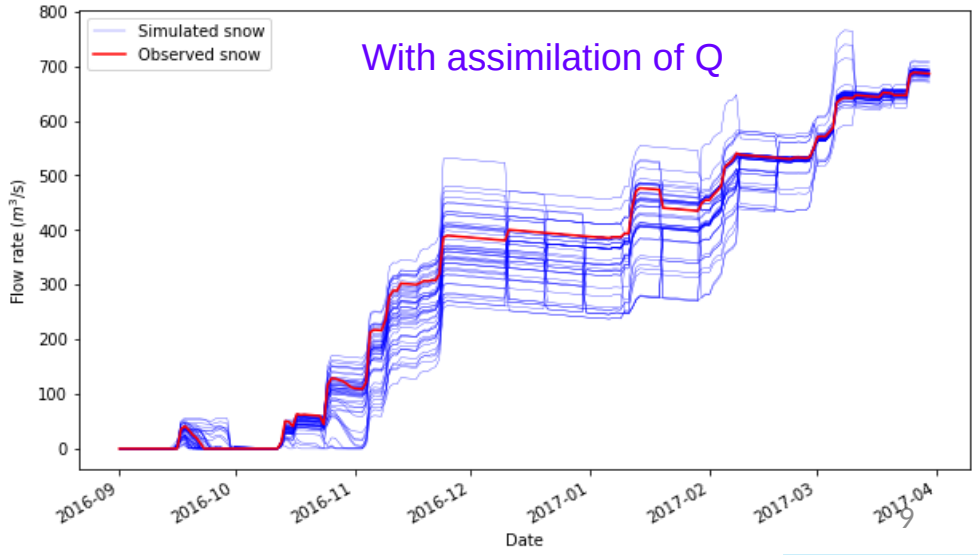
2 experiments:

- **Free ensemble** (50 particles) of simulation during winter period (from September to Marsh), **without** any **assimilation**, used as reference.

- **Resampled ensemble** (50 particles) using Particular Filter during winter period (from September to Marsh). Weights of particles calculated according **streamflow observations**. Assimilation cycle windows of 10 days.

Snow stock estimation





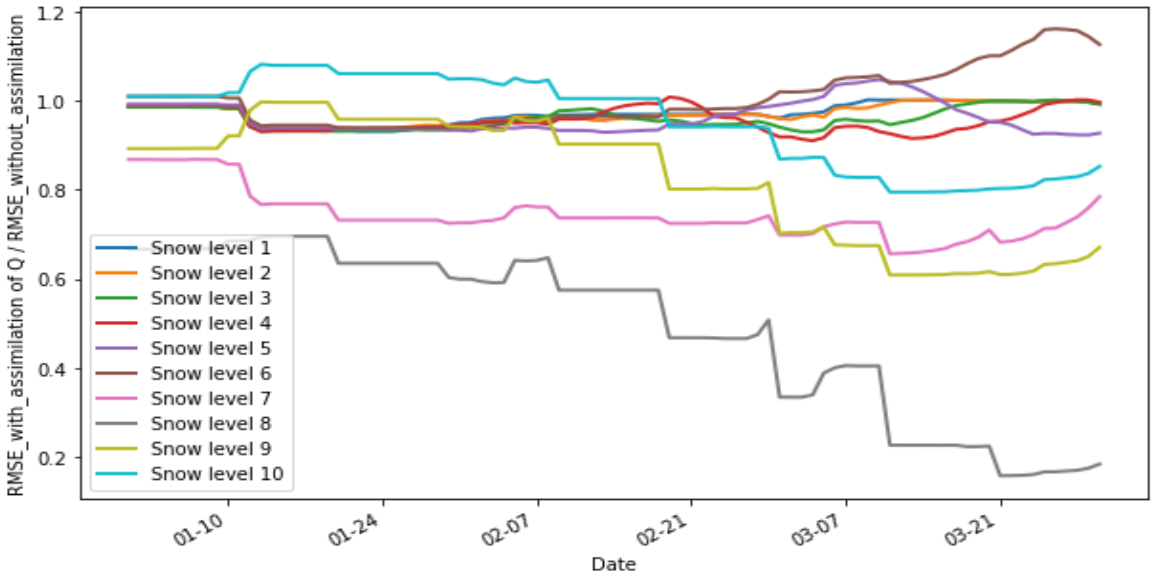
How does streamflow assimilation in winter improve snow stock estimates in end of winter

Assimilation of Q experiment

RMSE (simulated vs observations) of Snow amounts are calculated for each experiment

The ratio (RMSE_assim_Q / RMSE_ref) allow to observe potential benefit of the assimilation of Q, on the snow stock estimated at each level:

RMSE_assim_Q / RMSE_ref



Decrease of estimation **error** of **snow stock**, especially for levels **9**, **8** and **7**

Is the snow stock estimate improved by assimilating NRC?

Assimilation of S experiment

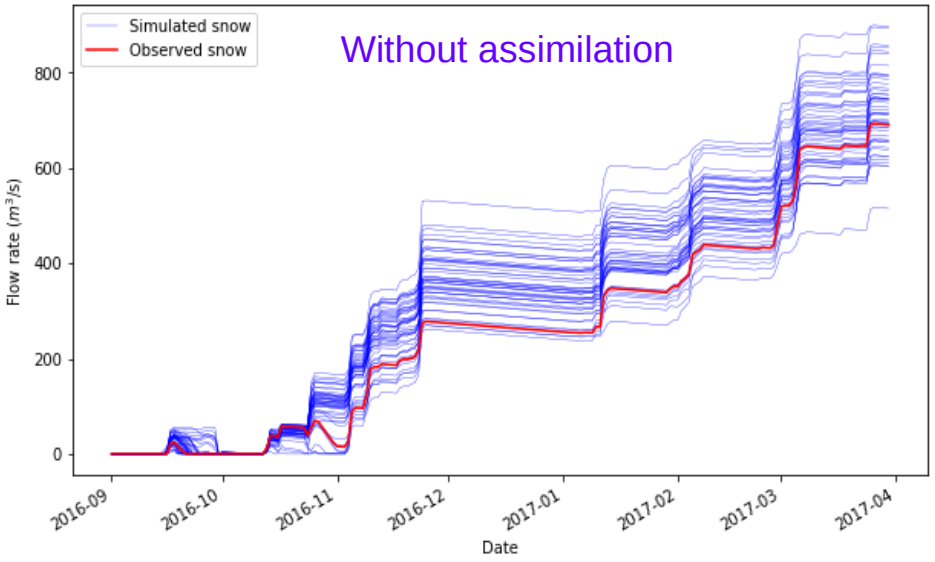
2 experiments:

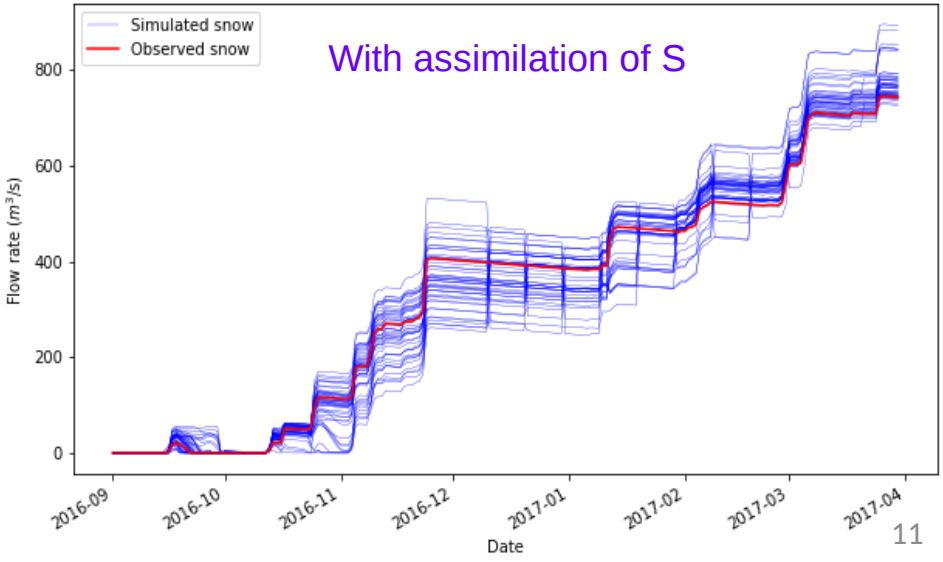
- **Free ensemble** (50 particles) of simulation during winter period (from September to Marsh), **without** any **assimilation**, used as reference.

- **Resampled ensemble** (50 particles) using Particular Filter during winter period (from September to Marsh). Weights of particles calculated according **NRC (snow amount) observations**. Assimilation cycle windows of 10 days.

Previous study (not shown) report level 8 simulations is most correlated level to the observations, then the level 8 is used to the weights calculation.

Snow stock estimation



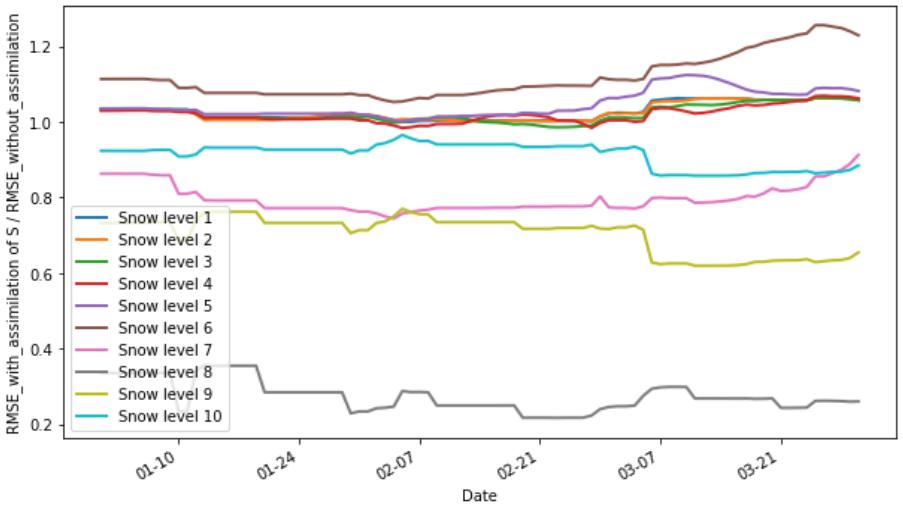


Is the snow stock estimate improved by assimilating NRC?

Assimilation of S experiment

The ratio (RMSE_assim_S / RMSE_ref) allow to observe benefits of the assimilation of S, on the snow stock estimated. The **benefit** is seen **from the beginning** of the assimilation at level **9**, **8** and **7**.

RMSE_assim_S / RMSE_ref

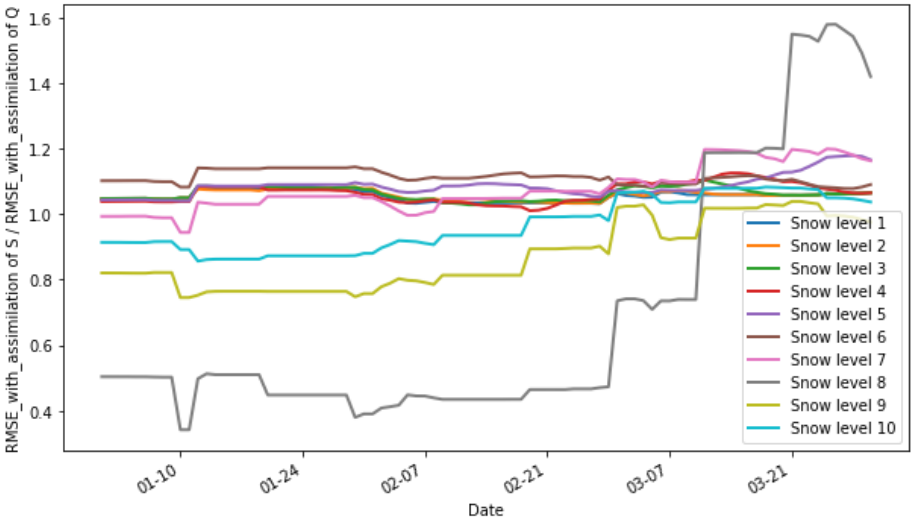


The ratio (RMSE_assim_S / RMSE_assim_Q) allow to compare the 2 assimilation configurations.

One can see during the **beginning up to February S assimilation** provides **better** results than Q assimilation. However, at the **end of the winter Q assimilation is better**.

Assimilation of S or Q do not bring the same benefits over the same periods.

RMSE_assim_S / RMSE_assim_Q



Conclusion

- It has been shown that the **Mordor** model is **very sensitive** to the initial **snow stock**, proving the importance of having a good estimate before starting a forecast.
- **Particular Filter** has been implemented within the MORDOR-SD model using a **Kitagawa resampling**.
- Experiments of **streamflow assimilation** report **benefit of snow stock** estimation, especially at the **end of the winter**.
- Experiments of **snow observations** (NRC) **assimilation** report **benefit of the snow stock** estimation, more or less **constantly throughout the assimilation period**.
- The assimilation of Q seems more beneficial at the end of winter, probably correlated with the melting period. It would be interesting to carry out a combined assimilation experiment of Q and S, and can be differentiated according to the temperature

  study the **variances of observations errors** as a **function of the temperature**?

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