Response to Reviewer #3

This paper investigates the dynamics of rock moisture in a sandstone cave and describes the relationship between rock moisture, surface and air temperature, and relative humidity and precipitation. The main and innovative methodology used by the authors is an FDR soil moisture probe to derive the dynamics of rock moisture. For the analysis of the influencing variables, the authors use 4 months of hourly data from one year as training data for an LSTM model to predict the hourly water content in the rock during 4 months in the second year. The most important results are that the water content in the rock is subject to seasonal fluctuations. It increases in seasons with high humidity and high temperatures. Using the SHAP values shows that precipitation is not used as a predictor variable by the LSTM. However, the LSTM has high prediction scores (NSE) based on measurements of humidity and temperature variables, which is consistent with theoretical principles.

(I am not a specialist in rock moisture dynamics or LSTM but understand a bit about modeling and ML techniques and am confident about my knowledge in field soil moisture measurements and soil vapor adsorption.)

In my opinion, the topic is very interesting and I agree with the authors that it is necessary to make progress in this field and to explore new measurement methods. Also, their results make a lot of sense from a theoretical point of view. Unfortunately, however, I have doubts about the methodology and data analysis which need to be addressed first before minor points could be discussed.

I suggest major revision for the following reasons:

TDR soil moisture probes have apparently been used already by other authors in this field to measure rock moisture dynamics (l. 48f, l.100f) but the authors state they "attempt to use the FDR for monitoring rock moisture in the field for the first time" (l.

56). Since this methodology is used in a new application setting, I strongly recommend giving more details about the sensor installation procedure. (l.97 ff). For me, it is not clear if the sensor is placed into holes drilled into the wall to be in close proximity/enclosed by the wall. This should be additionally added as a picture in Figure 2. I consider this an essential piece of information since it is known in the soil science community that contact between the sensor and (soil) parent material is crucial to obtain valid records of the (soil) moisture level.

Response: We totally agree that some previous studies (Mollo and Greco, 2011; Rempe and Dietrich, 2018; Sakaki and Rajaram, 2005) have used the TDR technique to monitor rock moisture, which have been cited in our manuscript. The difference between FDR and TDR has been mentioned in our manuscript. To the authors' knowledge, although the FDR technique has been widely used to monitor soil moisture, there is no previous application of FDR for rock moisture. Would you please tell us some previous application of FDR in rock moisture? Many thanks!

Following your suggestion, we will add the following picture of the installed sensor in Figure 2. We totally agree that the contact between the sensor and parent material is crucial to obtain accurate measurement. During the installation procedure, we use fine sand as infilling to make sure that the FDR sensor is in close proximity to the hole. We will add the details in the revision.

Figure S1. The FDR sensor in Cave #9.

Additionally, I feel more information is needed on the sensor's measurement sensitivity as well as the temperature sensitivity of the sensor. Although it is stated that FDR is "less influenced by temperature" (l. 55f) compared to TDR I suggest adding more information about the temperature effect. Ideally, a sensor calibration to temperature would be cited or performed under controlled conditions to exclude the possibility that Temperature has a dominant influence on the FDR reading, particularly because it varies only between 0.010 and 0.030 (1-3% volumetric moisture).

Response: We have conducted experiments by installing a FDR sensor into a rock specimen, which is placed outdoors. We do find the fluctuating temperature induced by sunshine caused significant temperature effect, showing increasing FDR signals with temperature.

In the current study, the FDR sensor is installed inside a cave. As shown in Figure 5, the wall temperature is quite stable in the summer. Because the sensor is close to the wall, we believe that the sensor temperature is close to the wall temperature. Figure S2 shows that in the periods with obvious rock moisture addition, there is no obvious correlation between apparent rock water content and wall temperature in either summer or winter. We will discuss why the temperature effect can be neglected in the revision.

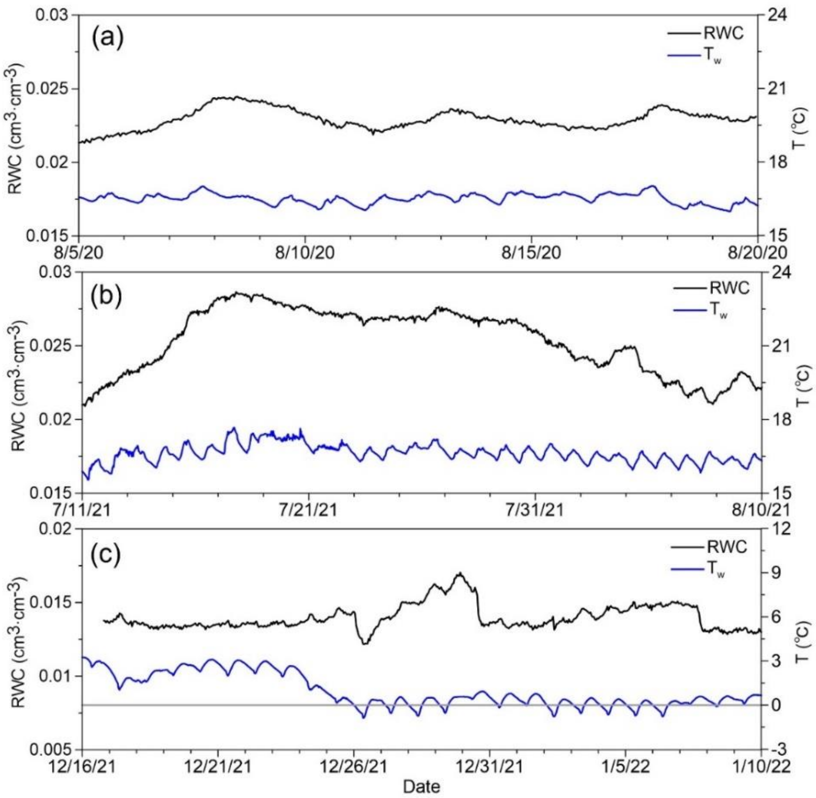

Figure S2. Some periods with obvious rock moisture addition. The rock moisture addition does not accompany increasing temperature.

The application of LSTM (as a Machine learning technique) is currently a hot topic and widespread in the scientific community but I am not sure if the use of this method is really necessary for the data analysis in this study. The results obtained from the LSTM have NSE scores as high as 0.958 and 0.97. From what I have been taught, such high scores usually need to be investigated very cautiously. Therefore, I wanted to clarify again that the LSTM was trained on a different period than the one shown in Figure 6? Please also provide information on the scores for the training data.

Response: Yes, the LSTM was trained on a different period than the one shown in Figure 6. We use the summer of 2020 as the training period and the summer of 2021 for testing. As shown in Figure S3, in the training period, the NSE of the Scheme #1 is as high as 0.988 and the NSE of the Scheme #2 is as high as 0.990.

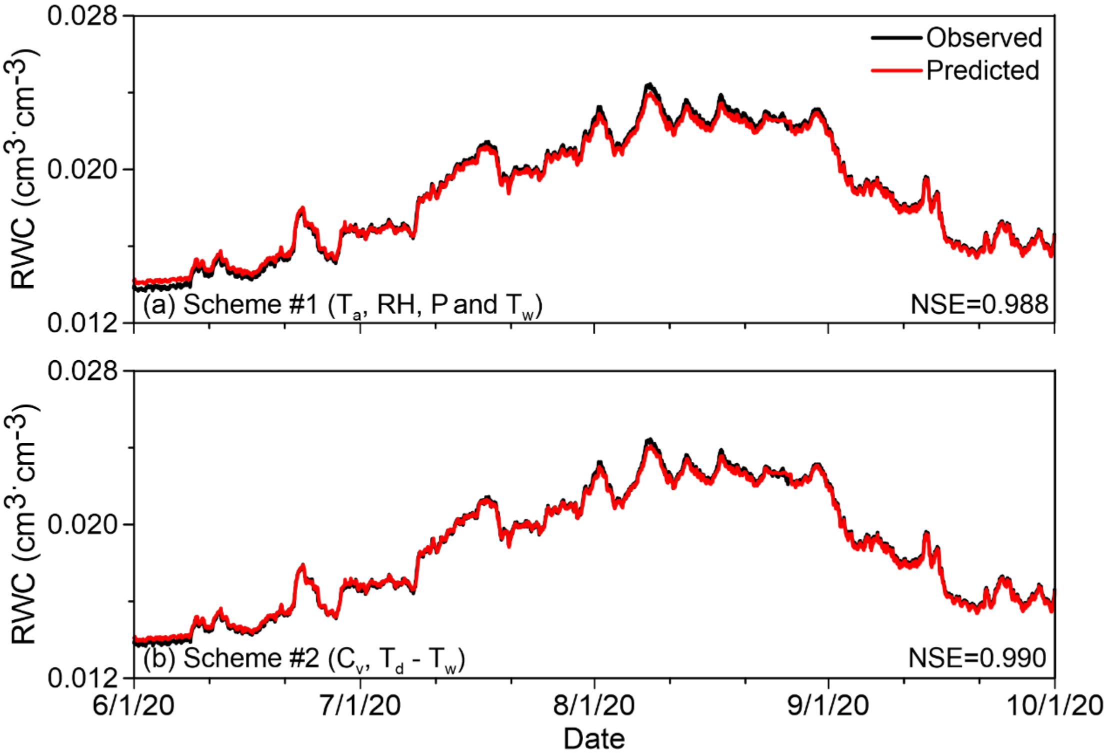

Figure S3. The result of training period of (a) scheme #1 and (b) scheme #2.

Another possibility for achieving in such high NSE would be, that the predictor variables are very highly correlated with the dependent variable (rock moisture), so the model has a very "easy task". I quickly reviewed the data from the .pdf document provided by the authors on Zenodo (only 226 observations because I copied them out of the .pdf format) and it looks like all variables are highly correlated and correlations are all significant. These results would question i) the need to use such a sophisticated method (LSTM) and ii) more generally, the validity of the FDR sensor data as used in this study (because of a possible temperature effect that is superimposed on the rock moisture measurement). I suggest to at least include additionally to the LSTM statistically more simple (and easier to interpret) scores of the relationship between all predictor variables and the rock water content.

Response: We agree that rock water content is highly correlated with humidity and air temperature. Table 1 shows the covariance between rock moisture and normalized atmospheric conditions in 2020 and 2021. The results show that each variable has a positive correlation with rock moisture. Vapor concentration (C_v) has the largest covariance while rainfall (P) has the lowest covariance. This is consistent with the feature importance obtained by the SHAP method. Although we did not predict rock moisture by using other classical statistical methods, we believe that the LSTM network, which is an emerging deep learning approach, has its unique advantages over other classical methods when it is combined with the SHAP method.

Table S1. The covariance between rock moisture and atmospheric conditions

	T_a	RH	P	T_w	C_v	T_d-T_w
2020	0.030	0.039	0.001	0.034	0.047	0.030
2021	0.043	0.034	0.001	0.036	0.044	0.022

We have tried to predict rock moisture using a RNN model with the same schemes. Although the results predicted by the RNN model is also acceptable (Figure S4), the resulting NSE is not as high as that obtained by the LSTM model. This is because the LSTM is a variant model that addresses the limitations of traditional RNNs by improving their ability to handle long-term dependencies. Therefore, we believe that the LSTM network as a deep learning model has its unique advantages.

The possible temperature effect has been discussed in our reply to the previous comment.

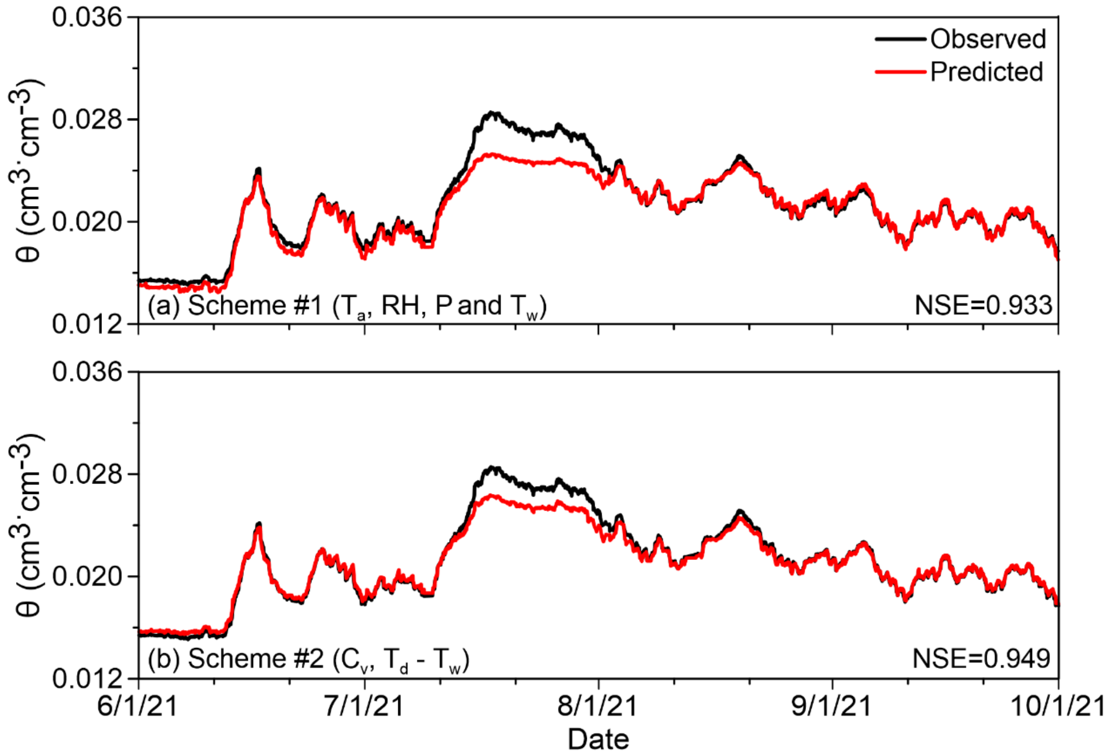

Figure S4. The predicted result of RNN by (a) scheme #1 and (b) scheme #2.

Therefore, before continuing the review process I strongly recommend to I) clarify the installation procedure of the FDR probe, ii) clarify the sensitivity of the instrument to temperature, and if the sensitivity is constant in time and iii) check for their whole data set, how strongly the variables are correlated to figure out if the use of LSTM is even necessary, or if the effect of the variables on the FDR reading is direct.

Response:

i) The installation procedure of the FDR probe has been clarified in our response and will be introduced in our revision.

ii) The possible temperature effect has been clarified in our response and will be introduced in our revision.

iii) The correlation between the variables has been revealed in our response and will be introduced in our revision.

iiii) The advantages of the LSTM network over the RNN network has been compared in our response and will be introduced in our revision.