Improving the accuracy of 1D SNMR surveys using the multi-central-loop configuration

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Improving the accuracy of 1D SNMR surveys using the multi-central-loop configuration

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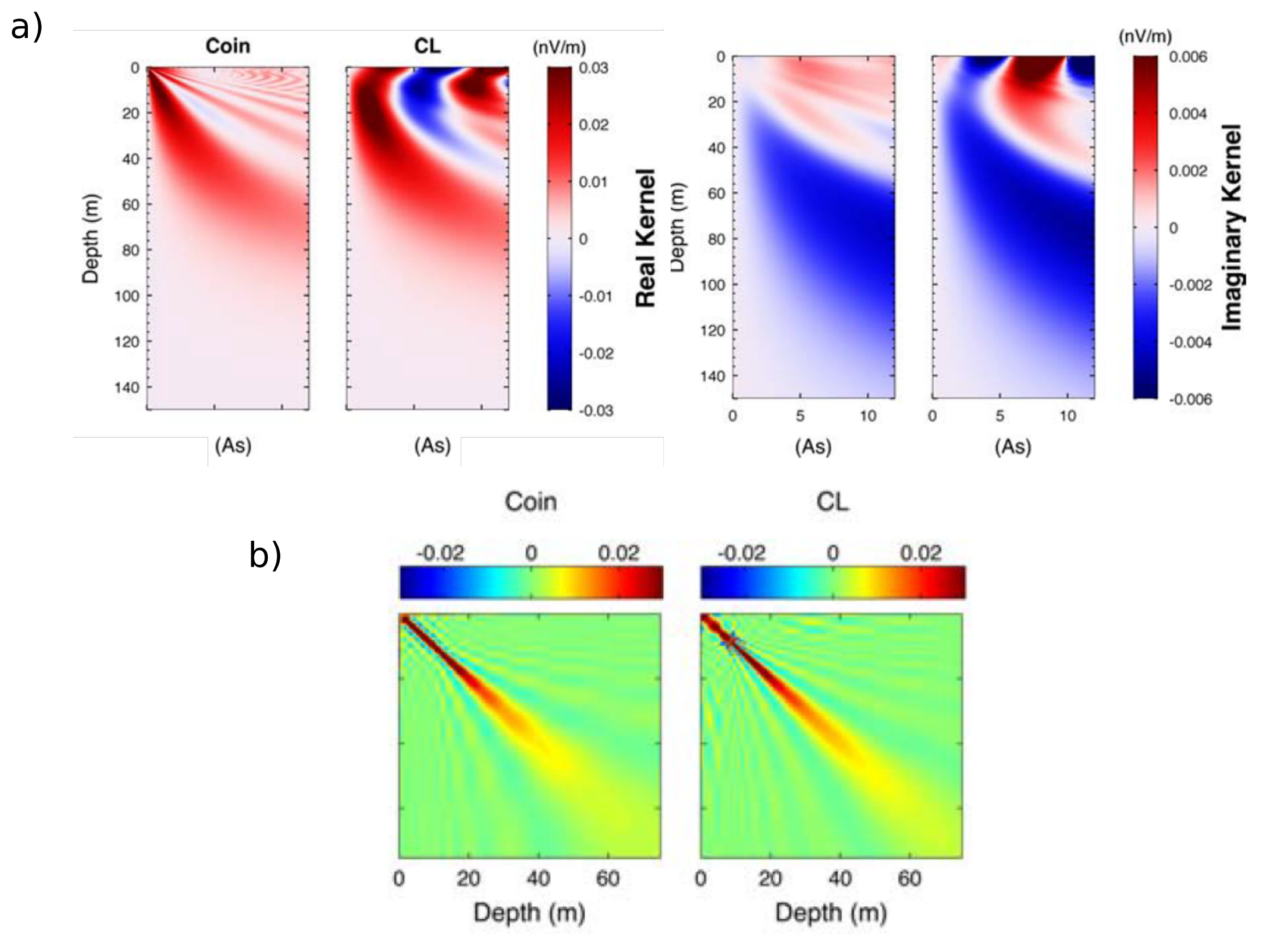
The central-loop configuration for 1D SNMR surveys, where the receiver loop is smaller than the transmitter loop was first presented by Berhoozmand et al. (2016). They compared its characteristics with the classical coincident-loop configuration, and demonstrated that it is superior on many aspects such as sensitivity distribution behavior, resolution at large depth and signal to noise ratio. Based on these findings, we investigate the potential of the multi-central-loop configuration, where several smaller receivers are placed within the transmitting loop, and all the data sets are processed and inverted together. The objective is to take advantage of the complementary resolution and sensitivity features of the different configurations, in order to improve the quality of the inverted model. We present here preliminary tests and results obtained with synthetic and field data.

Another possibility that would provide similar benefits and raise similar questions, is to invert simultaneously several data sets obtained independently (at different times), using varyin transmitter sizes or excitation pulse lengths. We investigate these aspects using a QT inversion approach (MRSMatlab, Muller-Petke et al., 2016). We acknowledge that the main challenge is to adapt the regularization of the inversion process, so as to handle correctly the noise originating from different data sets, although it seems less needed for the multi-central-loop configuration than for independent data sets. Finally, we introduce a new method for the interpretation of SNMR data based on statistical analysis of a large number of models, called the prediction-focused approach (PFA, Hermans et al., 2016). We observe that the efficiency of the method benefits from the use of the multi-central-loop configuration.

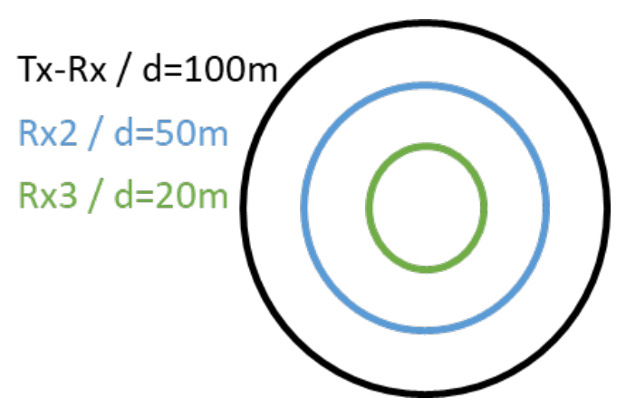
1. Central-loop configuration features



The central-loop (CL) configuration has benefits compared to the "classical" coincident loop configuration, as demonstrated by Berhoozmand et al. (2016). The complex kernels show additional sensitivity features in the shallow part (Fig. 1a). Also, resolution studies show that the CL configuration probes deeper than the coincident one when using complex data (Fig. 1b, modified after Berhoozmand et al. 2016).

2. Synthetic data

Multi-central-loop



The outer loop (d=100m) is used as a transmitter and a receiver, and the inner loops (d=50m and d=20m) are used as receivers only. Gaussian noise of 1500 nV amplitude is added to the data (scaling to the loop area), which corresponds to high noise conditions, with a signal to noise ratio of about 0.3.

a)

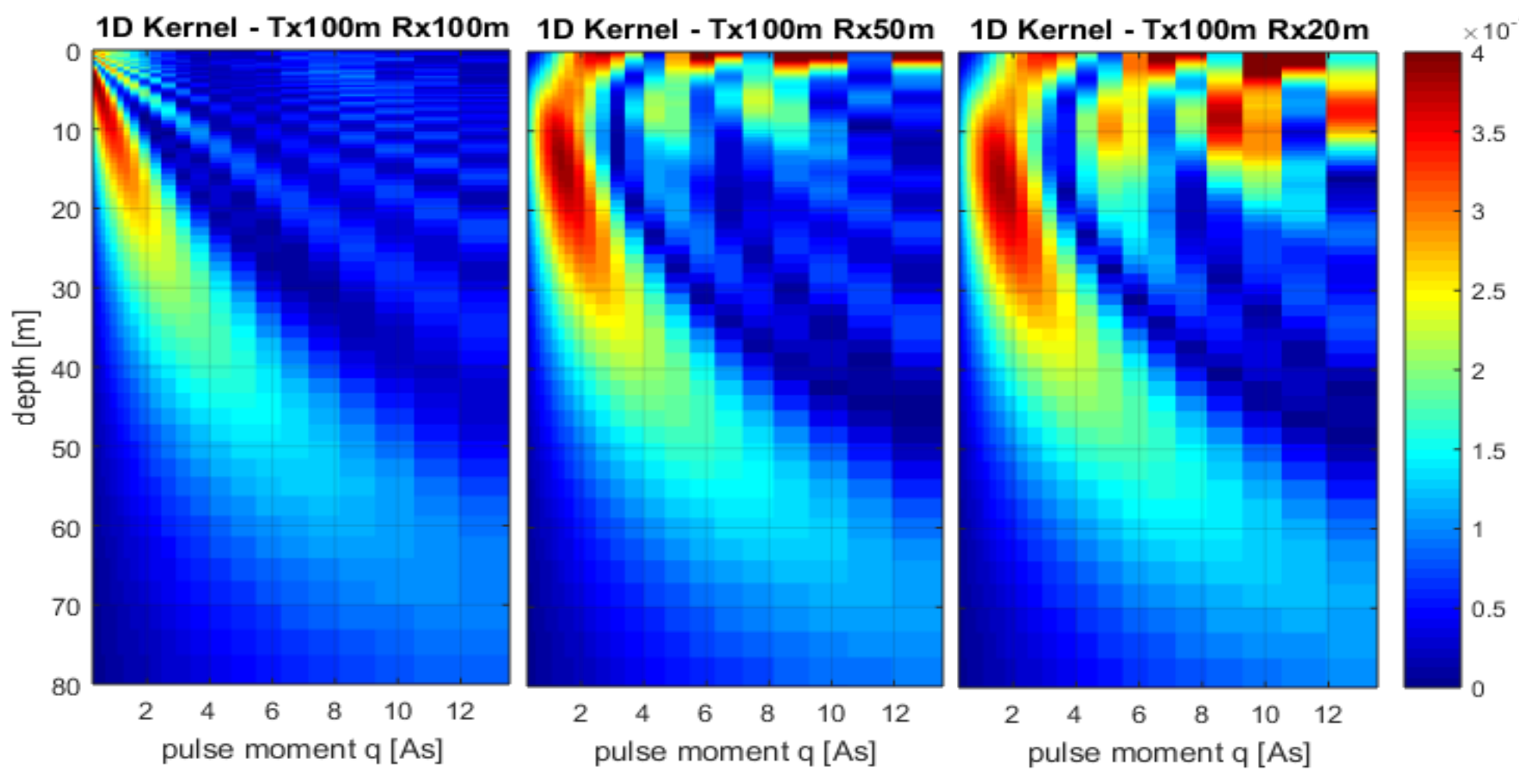
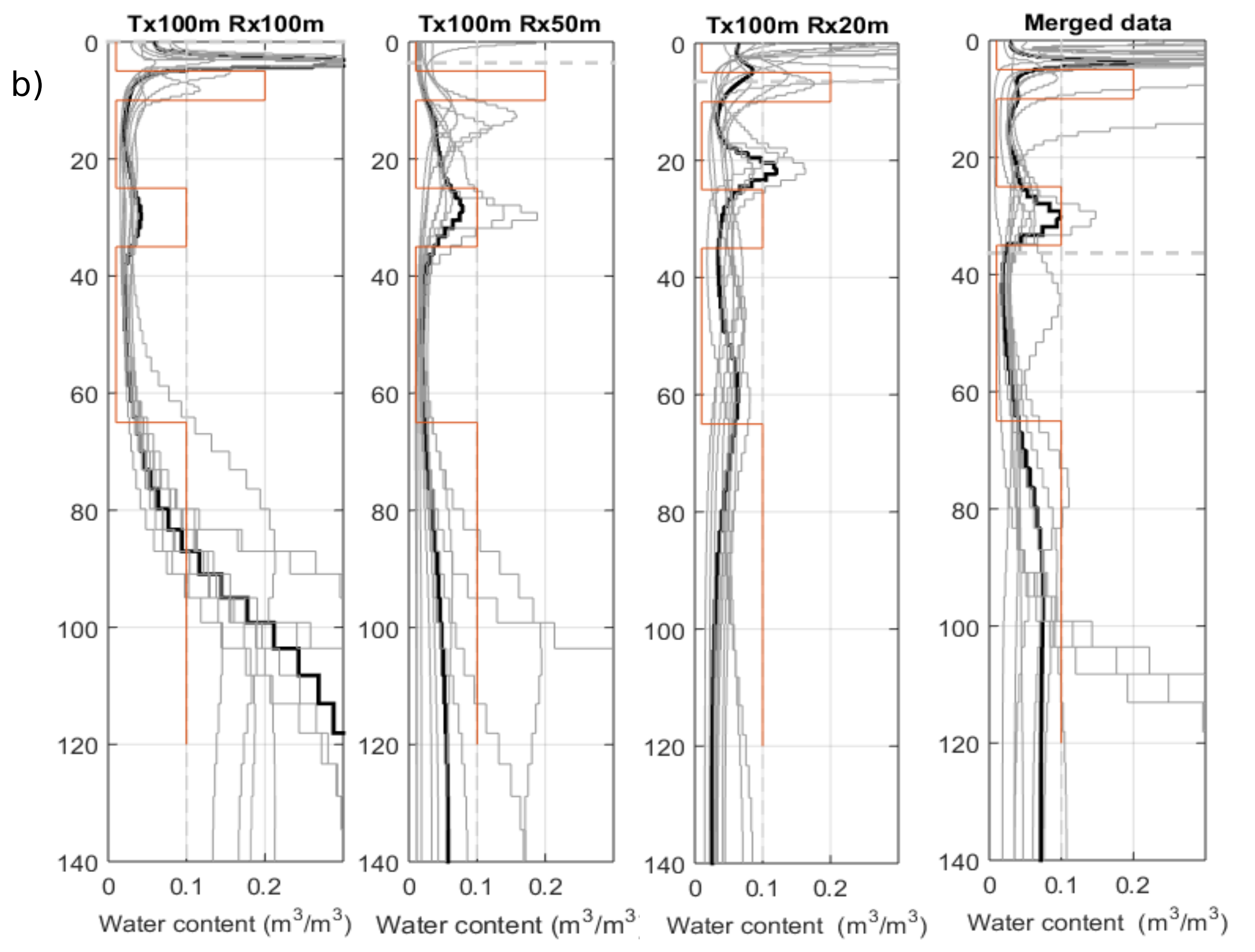


Fig. 2a shows the 1D Kernels computed for the three loop configurations (normalized to the receiver loop area for comparison). Synthetic data sets are generated based on the model from Fig. 2b. These data sets are first inverted independently then jointly (merged data). Inversions are carried out with the code MRSMatlab (Muller-Petke et al. 2016), using a QT aproach with complex data and mono-exponential fit. Regularization is chosen as high as possible while keeping a chi^2 value close to 1. Statistical runs are performed to assess the unecrtainty of the model.

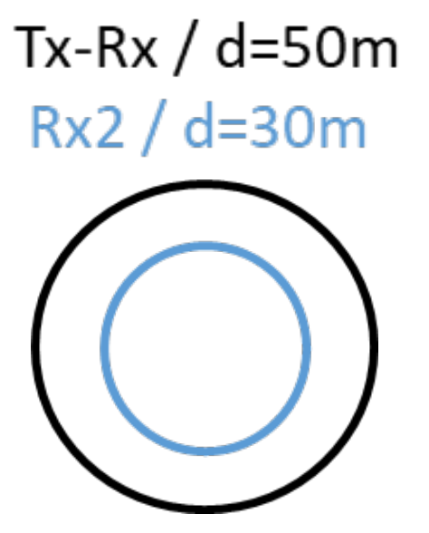
- In such high noise level contexts, the best reconstruction of the 3 aquifer model is obtained when using the multi-central-loop (merged) data (Fig 2b). All three structures are detected and the water content correctly estimated. However the uncertainty is stronger in some parts of the model.

b)

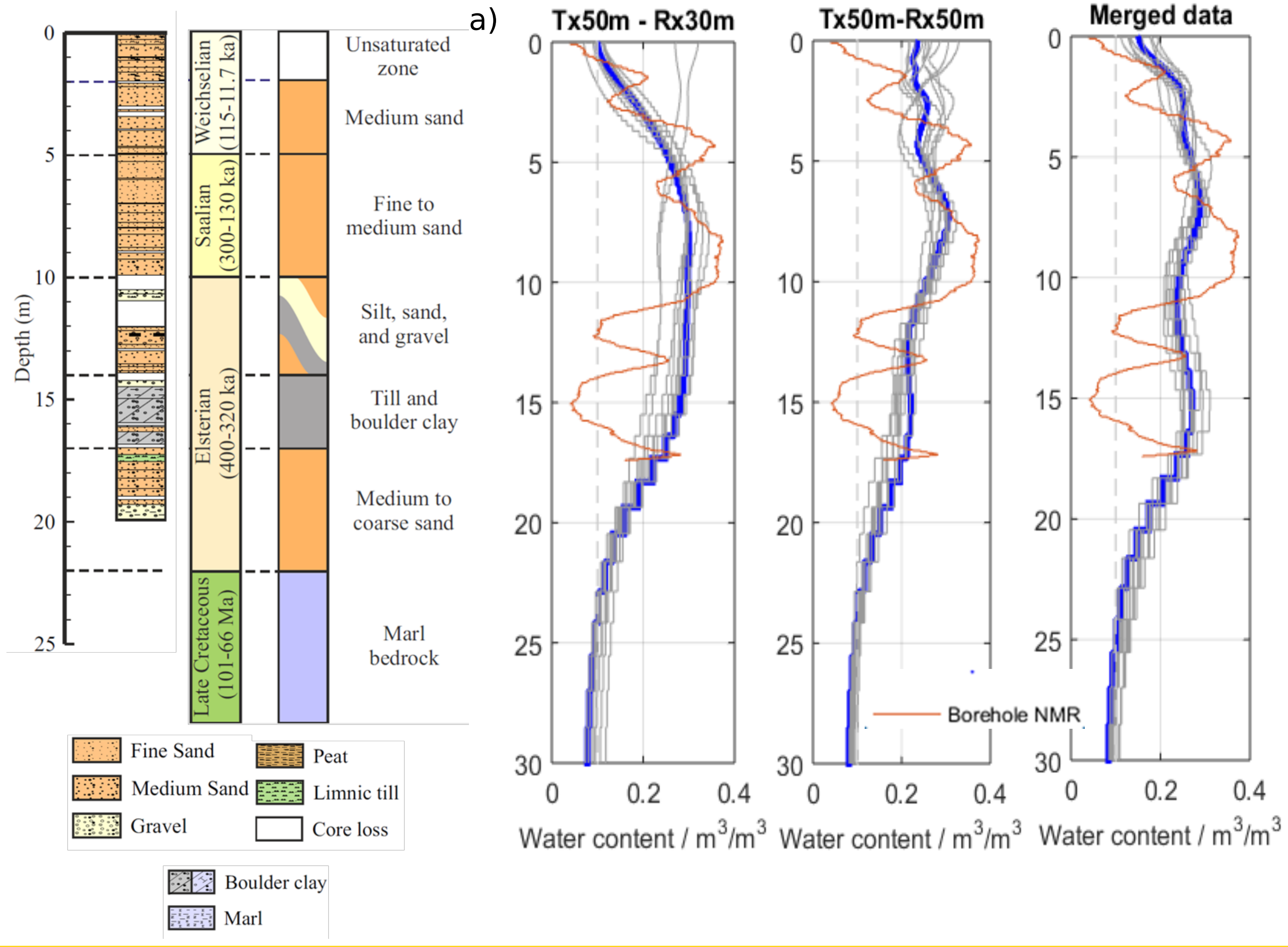


3. Multi-central-loop / REAL DATA / Independent data sets

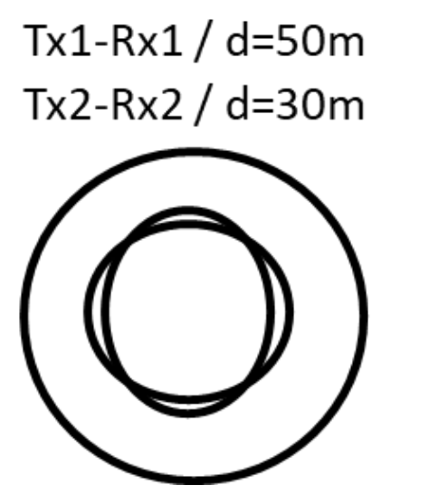
Multi-central-loop



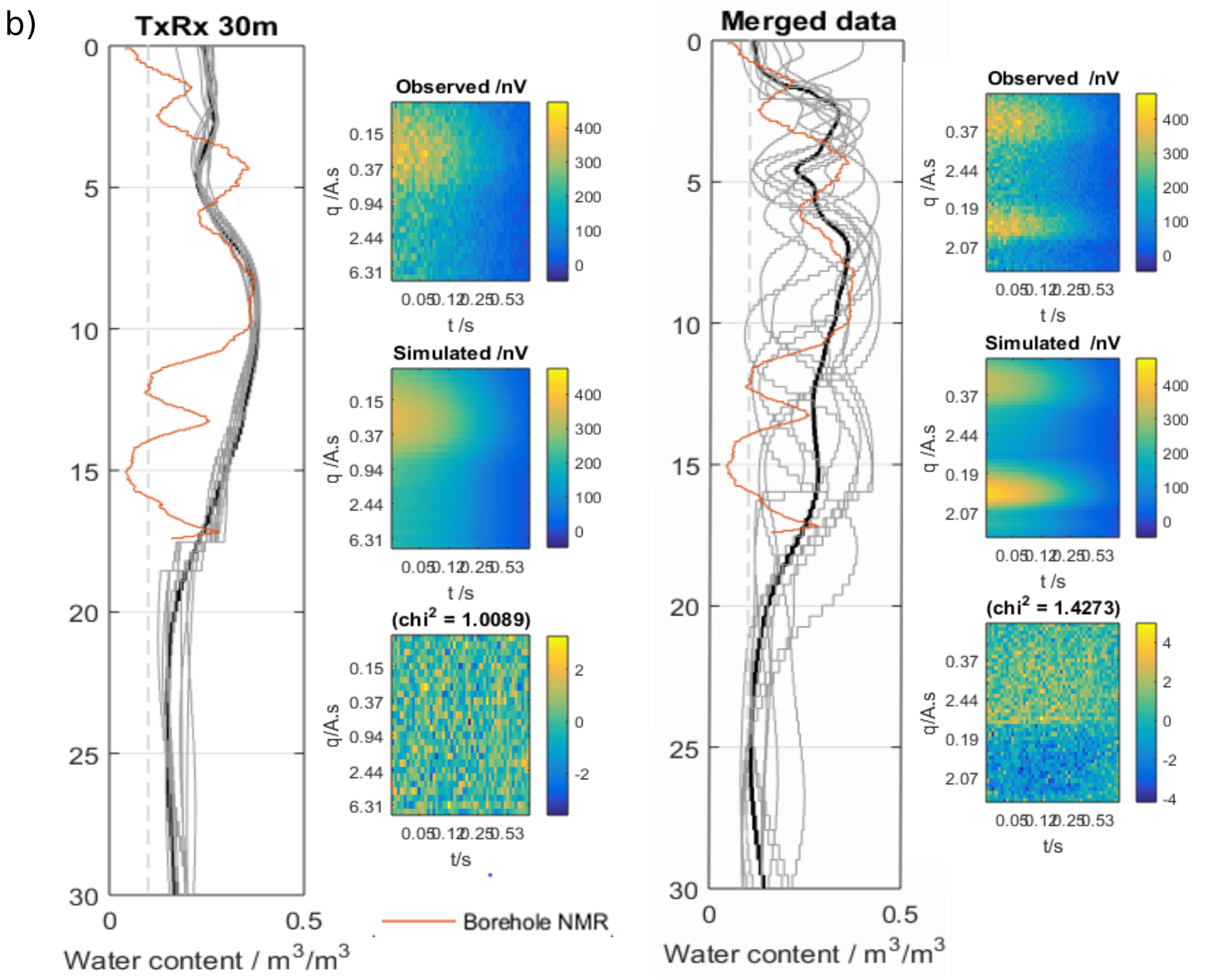
Multi-central loop data was acquired at the Schillerslage test site in Germany. A circular loop (d=50m) was used as a receiver and transmitter and a secondary loop (d=30m) was used as a receiver. Fig. 3a shows the results of the separated inversions and of the simultaneous inversion, with their uncertainty, against the mobile water content measured with borehole NMR (orange line). The merged data leads to an improved resolution of the water table without increasing uncertainties, and delinates three different structures, in accordance with the lithological log.



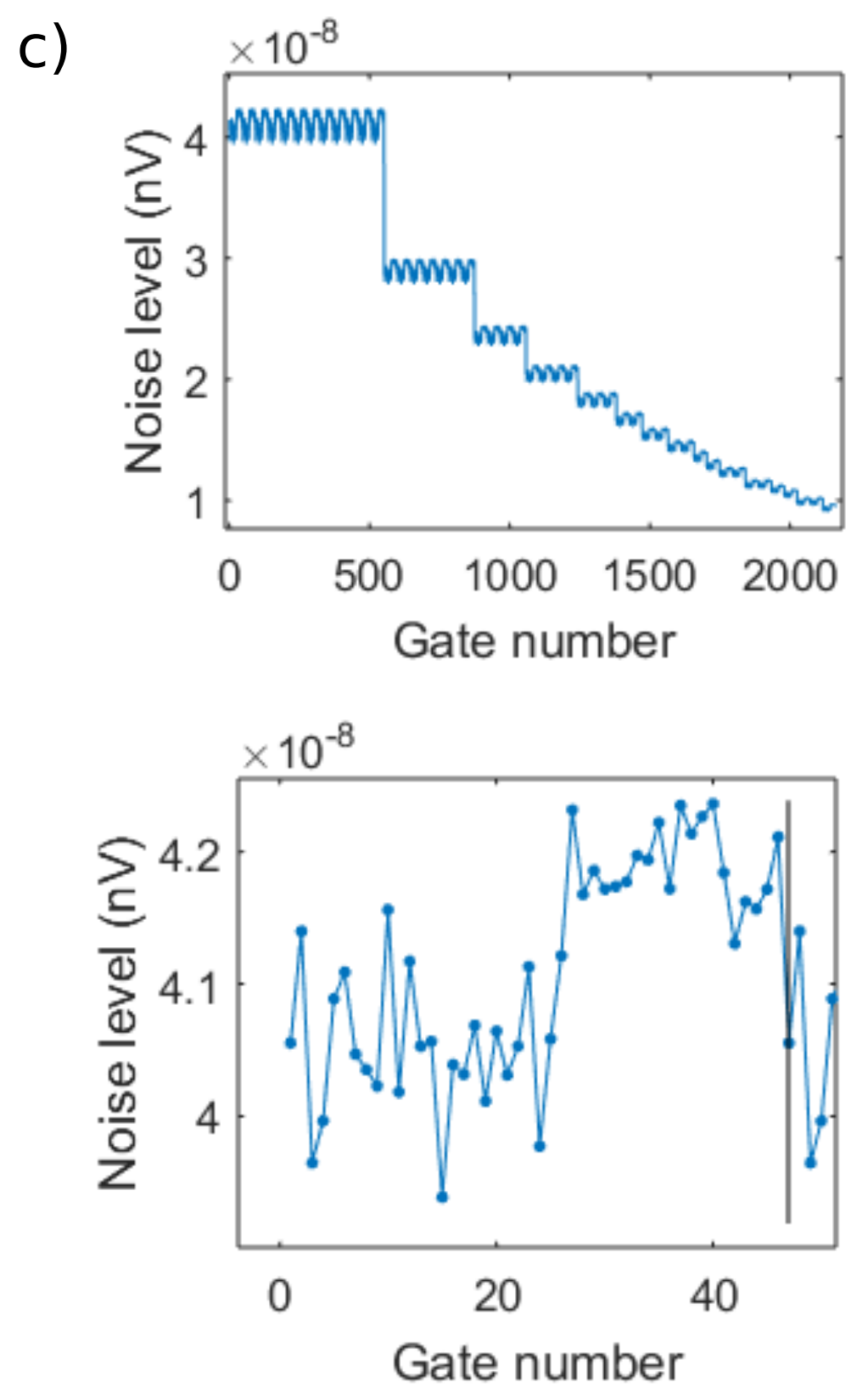
Independent data sets



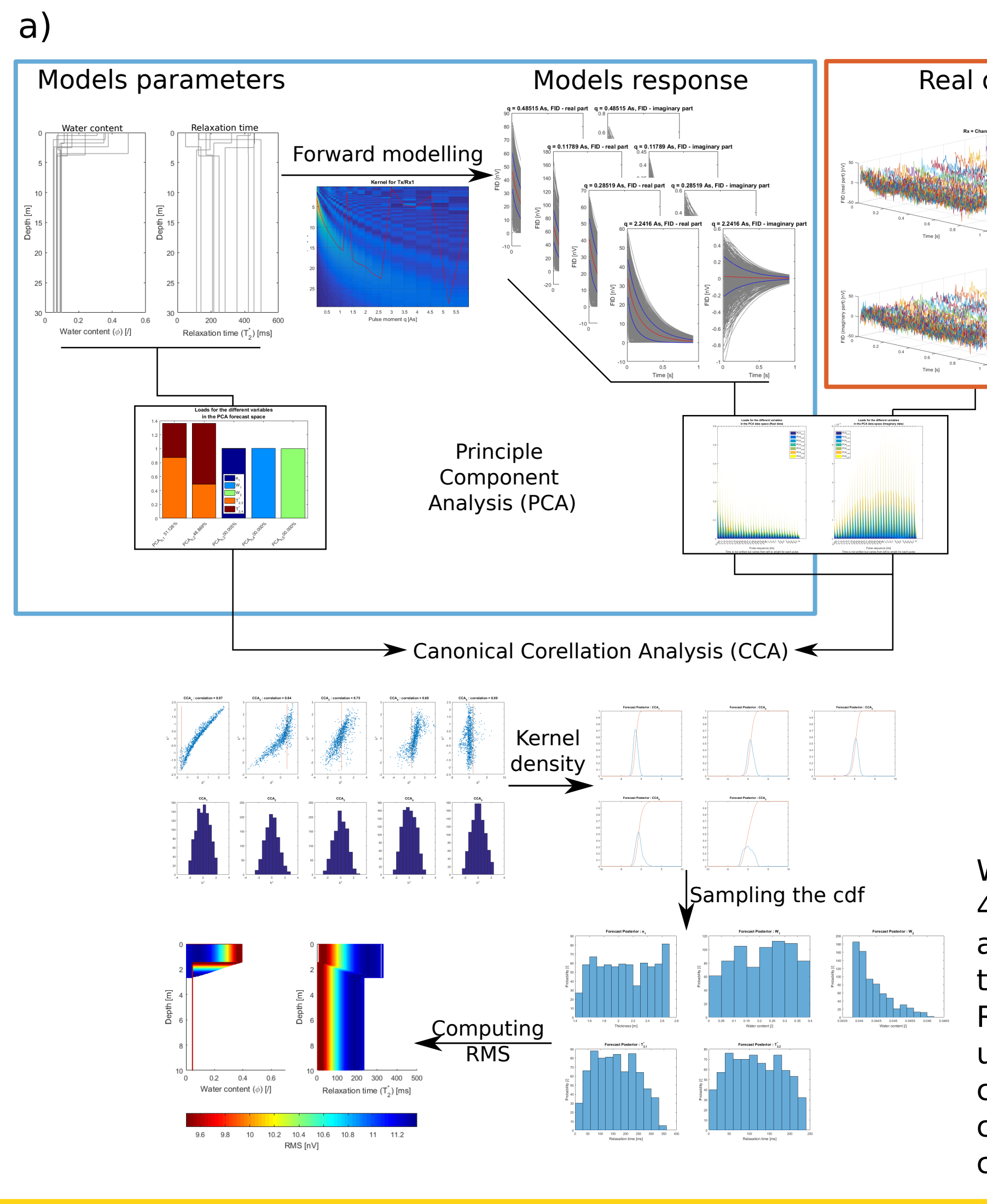
A second data set was acquired on the same day at the same location using a 2 turn 30m diameter loop for transmission. Fig. 3b shows the inversion results of this data set alone, and of the simultaneous inversion of the 50m loop data (Fig 3a-left) with this 30m loop data. The uncertainties are strongly increased, making the interpretation of the model much more difficult. The chi^2 value is high (1.42), indicating that the inverse model fails to fit correctly both data sets simultaneously.



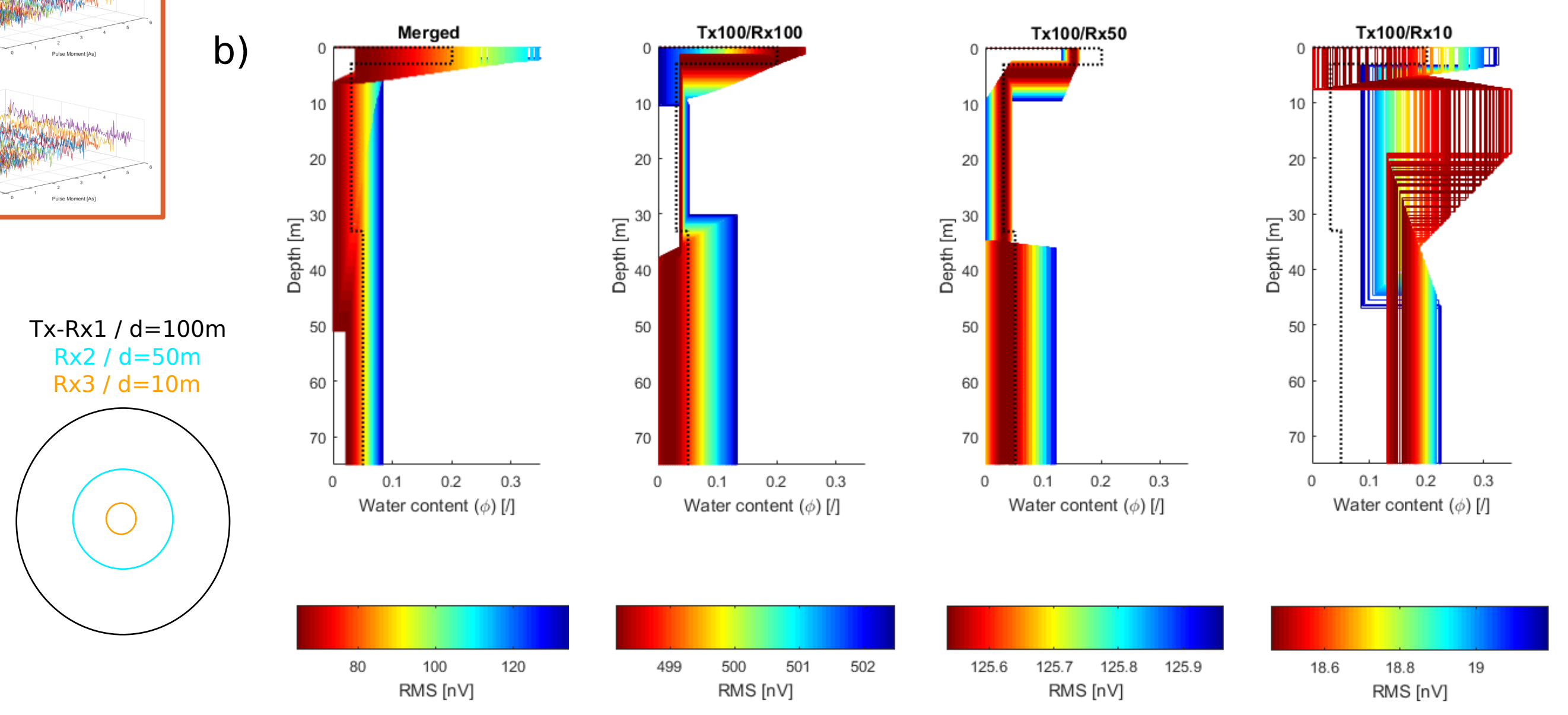
The loss in data fitting precision is likely due to a wrong weighting of the data due the different noise distribution of the two data sets. Fig. 3c shows the intial noise distribution used for data weighting, after time-gate integration



4. Prediction-focused approach



Prediction-focused approach is a new statistical method for the interpretation of geophysical data that does not require inversion of the data but rather relies on direct statistical relations between forecast variables and observed data (Fig. 4a) (Hermans et al., 2016).



We have successfully applied the method to a synthetic dataset originating from a synthetic model (Fig. 4b, dashed black line). Gaussian noise of 500 nV amplitude is added to the data (scaling the the loop area). The results (Fig. 4b) showed that the multi-central-loop configuration was advantageous to reduce the global uncertainty. Whereas the independent interpretations (Tx100/Rx100, Tx100/Rx50 and Tx100/Rx10) showed large uncertainties (on the thickness of the first layer for example), the merged case uncertainty is narrowed. Moreover, the envelope of possibilities from the merged case is the only one that contains the true model. The water content of the second layer is too large in the Tx100/Rx100 configuration and the water content of the first layer is too low in the Tx100/Rx50 one. The Tx100/Rx10 case clearly shows that the data from this receiver are not sufficent on their own.

5. Conclusion / Implications

- When the signal-to-noise ratio is low, the **multi-central-loop** configuration takes advantage of the varying sensitivity distributions and resolution capabilities of the separated configurations to better retrieve water content distributions. Model uncertainties can be affected by the simultaneous inversion, although we observe little deterioration with real field data.

- The **simultaneous inversion of independent data sets** leads to a strong increase of the inverted model uncertainty. Data weighting strategies must be applied to correctly handle the different noise distribution from each data set.

- The **Prediction-focused approach** is a promising method to interpret SNMR parameters without groing through an inversion process. It seems to benefit from the increase of information brought by the use of the **multi-central-loop** configuration

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