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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 Berhounzou et al. (2016). They compared its characteristics with the classical coincident-loop configuration, and demonstrated that it is superior in many aspects such as sensitivity distribution behavior, resolution at large depth and signal to noise ratio. Based on these findings, we investigated 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 varying 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
2. Synthetic data
3. Multi-central-loop / REAL DATA / Independent data sets
4. Prediction-focused approach
5. Conclusion / Implications

The central-loop (CL) configuration has benefits compared to the “classical” coincident loop configuration, as demonstrated by Berhounzou et al. (2016). The complex kernels show additional sensitivity features in the shallowest 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 Berhounzou 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 Hz amplitude is added to the data (scaling the the loop area). The results (Fig. 4c) showed that the multi-central-loop configuration was more effective to reduce the global uncertainty. Whereas the independent interpretations (1x10Hzx10 Hz) and 1x10 Hz10 Hz showed large uncertainties (on the thickness of the first layer for example), the merged view uncertainty is narrower. Moreover, the envelope of possibilities from the merged case is the only one that contains that of the CL. The water content of the second layer is too large in the 1x10 Hz configuration and the water content of the first layer is too low in the 1x10 Hz10 Hz case clearly shows that the data from this receiver are not sufficient on their own.

The complex kernels W,MRSmatlab—A software designed to evaluate the complex signal to noise ratio of magnetic resonance sounding data using a central loop configuration. Geophysical Journal International, 2021, 205:1-16
Muller-Petke, E., White, W., Hermans, T., Davis, E., & Casas, J. (2016). Direct prediction of spatially and temporally varying physical properties from magnetic resonance data. Near Resour Resour, 2016, 2016:

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A second data set was acquired on the same day at the same location using a 3.2 km 30m-diameter loop for transmission. Fig. 2a shows the results obtained that day. The water content of the second layer is too low in the TxK660RxK66 configuration as demonstrated by Fig. 2c, showing the inversion results of this data set alone. The water content of the second layer is too large in the TxK660RxK66 configuration and the water content of the first layer is too low in the TxK660RxK66 configuration. The uncertainty of the model is also too low in the independent interpretation of the model. The chi^2 value is high (1.4), 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 transmission areas. The chi^2 value is high (1.4), indicating that the inverse model fails to fit correctly both data sets simultaneously.

In such high noise levels context, the best reconstruction of the 3 aufer 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 higher than in some parts of the model.

Another possibility that would provide similar benefits and raise similar questions, is to invert simultaneously several data sets obtained independently (at different times), using varying 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.

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 going through an inversion process. It seems to benefit from the increase of information brought by the use of the multi-central-loop configuration.

We have successfully applied the method to a synthetic dataset originating from a synthetic model (Fig. 4b, dashed black line). Gaussian noise of 500 Hz amplitude is added to the data (scaling the the loop area). The results (Fig. 4c) showed that the multi-central-loop configuration was more effective to reduce the global uncertainty. Whereas the independent interpretations (1x10Hzx10 Hz) and 1x10 Hz10 Hz showed large uncertainties (on the thickness of the first layer for example), the merged view uncertainty is narrower. Moreover, the envelope of possibilities from the merged case is the only one that contains that of the CL. The water content of the second layer is too large in the 1x10 Hz configuration and the water content of the first layer is too low in the 1x10 Hz10 Hz one. The 1x10Hzx10 Hz case clearly shows that the data from this receiver are not sufficient on their own.

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