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Improve NMR estimation of water content and distribution in unsaturated bedrocks

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Nuclear magnetic resonance (NMR) has been widely used in near-surface geophysics due to its direct sensitivity to water. As a field form of NMR, borehole NMR has been applied to in situ hydrological investigations for decades. However, the recent implementations of borehole NMR to unsaturated zones face challenges due to the complex geology. Due to the fast operation speed and unsaturated conditions in critical zones, the raw NMR signals often suffer from limited relaxation time ranges and low signal to noise ratios. Such low quality of raw data can induce artifacts during inversion and following data interpretations. This study investigates the long-overdue evaluations of how the low borehole NMR data quality affects water distribution estimation in unsaturated zones. A synthetic analysis based on lab NMR data was first performed to simulate the inversion errors induced by the low-quality borehole NMR data. Lab NMR measurements were conducted on carbonate and shale samples from a well that has a corresponding borehole NMR profile. In order to match the low signal-to-noise ratio and data size of the low-quality borehole NMR data, lab NMR data points were reduced, deadtime was increased and normally distributed noise was added. The inversion results of the synthetic data reveal that the low signal to noise ratio leads to an overestimation of signals at lower relaxation time while the limited relaxation time range does not significantly affect the total water estimation. To improve the water estimation from the low-quality borehole data, a peak decomposition and peak fusion method were then applied to the synthetic data. Relaxation time distribution of both lab and synthetic data were decomposed into multiple normally distributed peaks. The first peak with the shortest relaxation time from lab NMR was used to substitute the first peak of the synthetic borehole NMR relaxation time distribution. After peak decomposition and fusion, the predicted water contents were closer to lab NMR than original synthetic data. This study reveals the mispredictions of water distribution due to the low data quality of borehole NMR. The success of improving water content estimation on the synthetic study has clear implications that the peak decomposition and peak fusion method can be applied to actual borehole NMR data to improve water content and distribution estimation in unsaturated zones.