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Layer-optimized synthetic aperture radar processing with a mobile phase-sensitive radar: a proof of concept for detecting the deep englacial stratigraphy of Colle Gnifetti, Switzerland and Italy

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S1 Comparison of processing methods

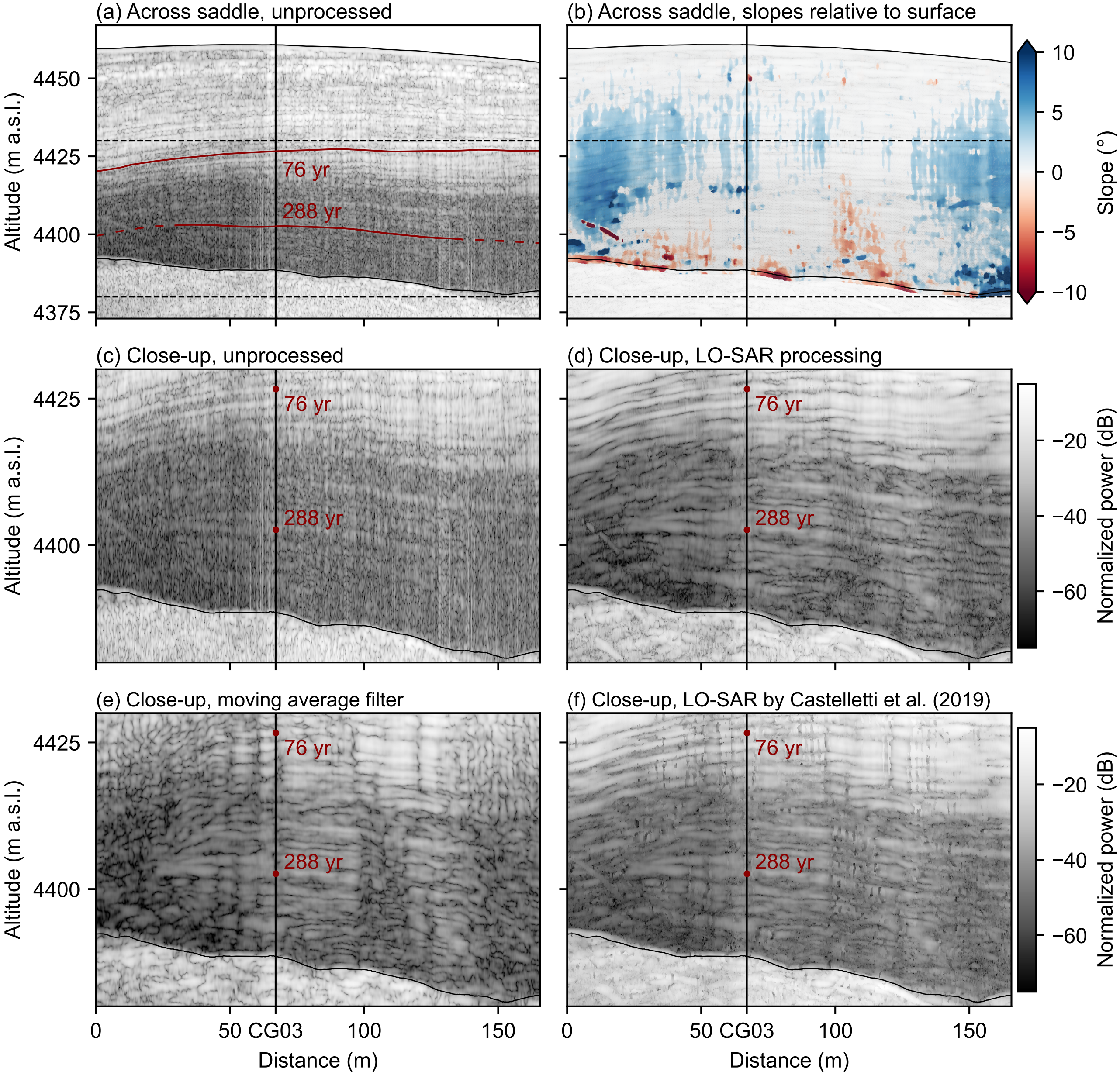

Figure S1. Comparison of processing methods for across saddle radargram. (a) Unprocessed mobile pRES data and (b) englacial slopes relative to surface. (c–f) Close-up view of deep stratigraphy. (c) Without processing, (d) with LO-SAR processing as implemented in this study, (e) with moving average filtering and (f) with LO-SAR processing as implemented by Castelletti et al. (2019). The location of the CG03 ice core and traced IRHs are marked. Coherent averaging results in destructive interference where IRHs are sloped. Both LO-SAR processing approaches provide improved imaging of the deep stratigraphy. Closely spaced IRHs are better resolved by integrating the power along IRH slopes during LO-SAR processing (d), because destructive interference at the boundary between IRHs is amplified.

Phase-coherent radar processing techniques can either enhance or diminish radar imaging capabilities. Figure S1 compares layer-optimized synthetic aperture radar (LO-SAR) processing, as implemented in this study, to moving average filtering and LO-SAR processing as implemented by Castelletti et al. (2019). In our LO-SAR processing implementation, the backscattered power is coherently integrated along internal reflection horizons (IRHs) after estimating their slopes (Fig. S1b). The other two methods integrate power along range bins, with (LO-SAR processing by Castelletti et al. (2019), Fig. S1f) and without (moving average filtering, Fig. S1e) correcting for along track phase gradients. Castelletti et al. (2019) compute the required phase shift by point-wise optimization of the signal-to-noise ratio. Here, we approximate their implementation by using the unfiltered slope estimates from our approach to correct for phase gradients in the raw signal before applying coherent integration along range bins. For all three processing methods, a synthetic aperture length or filtering window of $L_{\mathrm{SAR}} = 5\ \mathrm{m}$ is used.

Moving average filtering results in signal extinction due to destructive interference where IRHs are sloped. This is avoided during LO-SAR processing by correcting for the horizontal phase gradient associated with the IRH slopes, resulting in improved imaging of the deep englacial stratigraphy compared to the unprocessed data. In our LO-SAR implementation, the slopes of IRHs are initially estimated. This facilitates filtering these slopes prior to the coherent integration of power to remove outliers that for example occur at the boundary between two IRHs. Moreover, coherent summation can be performed directly along the englacial slopes. In this way, closely spaced IRHs are better resolved as the constructive interference at IRH centers and destructive interference at the IRH boundaries are enhanced.

References

Castelletti, D., Schroeder, D. M., Mantelli, E., and Hilger, A.: Layer Optimized SAR Processing and Slope Estimation in Radar Sounder Data, J. Glaciol., 65, 983–988, https://doi.org/10.1017/jog.2019.72, 2019.