The Potential for Full-Waveform Lidar in SnowEx Studies

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Full-waveform Lidar

Full-waveform (FWF) lidar data provide a near continuous waveform response as opposed to points captured with discrete return lidar (Fig 1). Considering vegetation as a target, a waveform response has the potential to provide detailed information about the canopy structure and function. However, the increased waveform information as compared to point clouds (see Fig 2a, b) can be computationally challenging. We developed a waveform processing workflow using NASA JPL's Airborne Snow Observatory (ASO) data collected in Reynolds Creek Experimental Watershed (RCEW) (Fig 3). This workflow begins with the raw waveform data from the instrument and results in the output of several waveform metrics that can be used to describe the canopy structure and function (Fig 4).

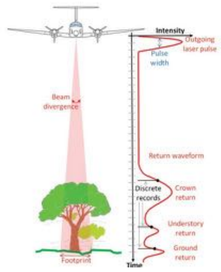


Figure 1. Conceptual diagram of waveform and discrete lidar.

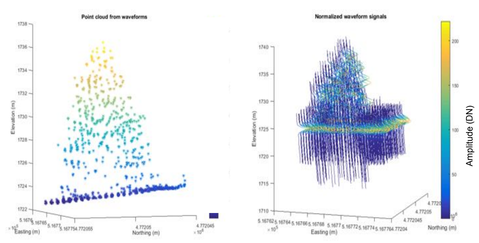


Figure 2. Juniper tree characterized by a) discrete lidar points and b) waveform lidar.

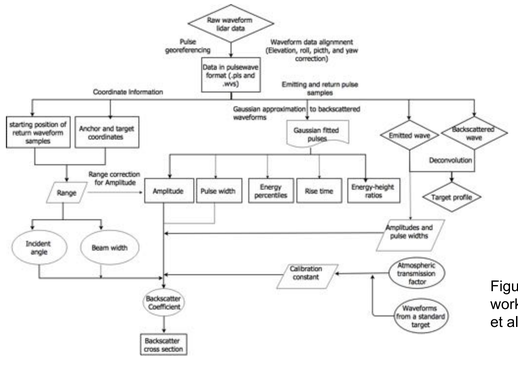


Figure 3. Waveform processing workflow developed by Ilangakoon et al. (2018).

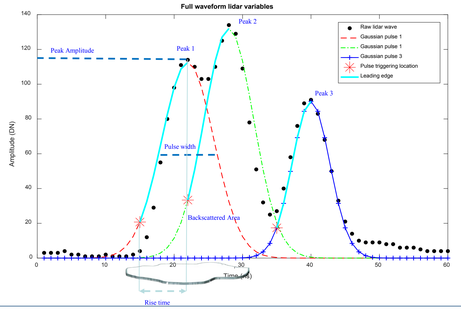


Figure 4. Example parameters that can be retrieved from waveforms (Ilangakoon et al., 2018).

Example Full-waveform Analysis

Using the workflow presented in Fig 4, we developed new techniques to differentiate plant functional types (PFTs) (Fig 5), leaf area index (LAI) (Fig 6), and a series of functional traits (Fig 7) and diversity (Fig 8) for RCEW with the FWF. We compared the latter with simulated FWF from NASA's GEDI on the International Space Station..

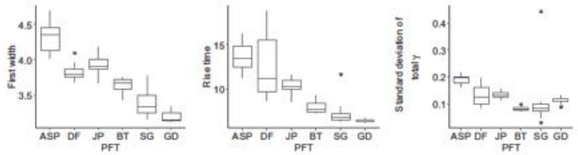


Figure 5. First width, rise time, and standard deviation of total backscatter are used to differentiate PFTs, including aspen, Douglas Fir, juniper, bitterbrush, sagebrush, and ground.

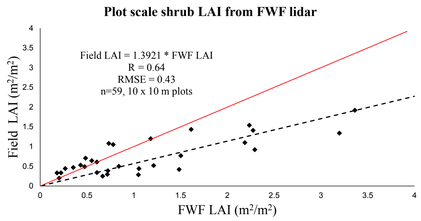


Figure 6. FWF lidar can also be used to estimate LAI. In this example, FWF was used to estimate LAI of shrubs in RCEW with strong predictive power.

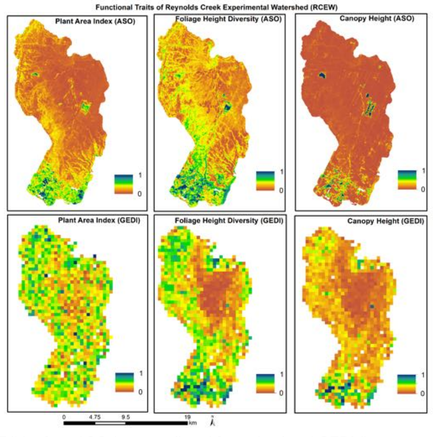


Figure 7. The FWF lidar from ASO (top panel) and from simulated GEDI (bottom panel) are used to estimate functional traits across RCEW (Ilangakoon et al., in prep).

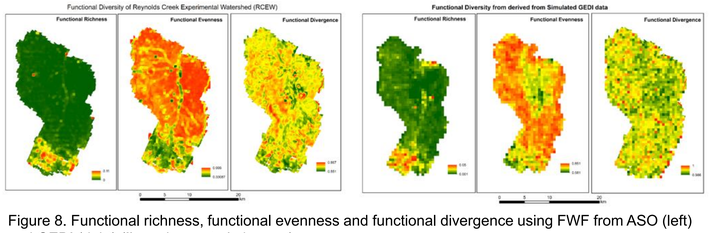


Figure 8. Functional richness, functional evenness and functional divergence using FWF from ASO (left) and GEDI (right) (Ilangakoon et al., in prep).

Opportunities for Snow-Ex

Full-waveform lidar at Grand Mesa was collected by ASO in snow-off (Fall 2016) and snow-on (February 8, 2017), as part of SnowEx. There are a number of opportunities for this dataset:

1) <u>Separating ground from shrub</u>. Several studies have found significant errors in snow depths from lidar in regions with shrubs. Separating ground from shrubs is difficult in discrete return lidar and our models demonstrate that FWF can improve on this differentiation at both fine (1 m) and coarser (10 m) scales (Fig 9).

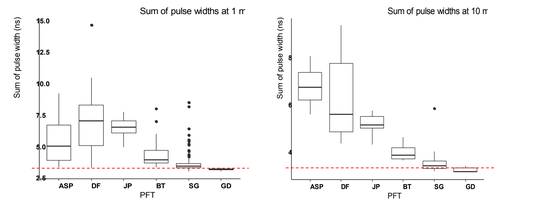
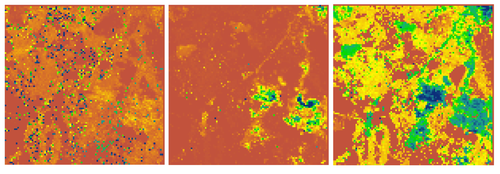


Fig 9. Pulse width separates ground from vegetation (even with shrub heights < 1m)

2) <u>Understanding relationships between vegetation and snow depth and extent.</u> Preliminary studies (Malekshah et al.) indicate that vegetation metrics such as foliar height diversity (FHD), a measure of the arrangement of the canopy layers, has a significant influence on snow depth. FWF is especially well suited to mapping FHD at a variety of scales (Fig 10).



Effective Leaf Area Index (LAI) | Max vegetation height | Foliar Height Diversity (FHD)

Figure 10. Example vegetation metrics derived from FWF, including LAI, vegetation height, and FHD (left to right).

3) <u>Satellite-base lidar to understand relationships between vegetation and snow depth.</u> While limited in coverage, we can test the potential of space-based FWF lidar to detect snow – canopy interactions using GEDI. Preliminary work at RCEW indicates that GEDI overestimates shrub heights (Fig 11) but is expected to perform better with forested ecosystems in snow-dominated mountain watersheds.

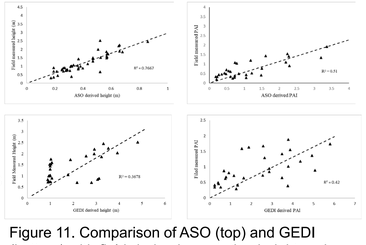


Figure 11. Comparison of ASO (top) and GEDI (bottom) with field-derived vegetation height and plant area index (PAI) in shrub.

References & Acknowledgements

References
Ilangakoon, N., Glenn, Nancy F; Dashti, Hamid; Painter, Thomas H; Mikesell, Dylan; Spaete, Lucas P; Mitchell, Jessica; Shannon, Kyle, 2018, Constraining plant functional types in a semi-arid ecosystem with waveform lidar, Remote Sensing of Environment, 209, 497-509.
Ilangakoon, N., Nancy Glenn, Fabian D Schneider, Steven Hancock, Hamid Dashti, Lucas Spaete, Tristan Goulden, Trends and patterns of functional diversity and disturbances in semi-arid environments:opportunities for airborne and global lidar observations, in prep.
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