Estimating snow properties with L-Band InSAR: results from the NASA SnowEx campaign

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Abstract

Previous research on estimating snow water equivalent (SWE) using microwave radar has traditionally focused on observations at X- and Ku-bands, for which the wavelength is approximately an order of magnitude larger than the snow grain size, and have used the volume scattering signal to estimate snow mass. At lower frequencies such as L-band, dry snow is nearly transparent, with very little volume scattering occurring within the snowpack. While this causes very little change in radar amplitude with changes in snow mass, the additional snow mass causes a change in the time-of-flight of the radar signal, leading to an observable change in phase. We explore the use of L-band InSAR for estimating changes in SWE, using data recently collected as part of the NASA SnowEx campaign.

Introduction

- UAVSAR L-Band InSAR acquisitions on February 22 and February 6, during NASA SnowEx 2017 campaign on Grand Mesa
- LiDAR snow free flight on September 26, 2016 and snow-on Feb 8 and Feb 25, during NASA SnowEx 2017
- Very small change in SWE (0-5cm) and depth (0-20cm) during SnowEx 2017
- L-band InSAR phase change shows similar patterns to LiDAR snow depth on Western part of Grand Mesa in open areas
- L-band InSAR amplitude shows large differences between open areas and vegetation

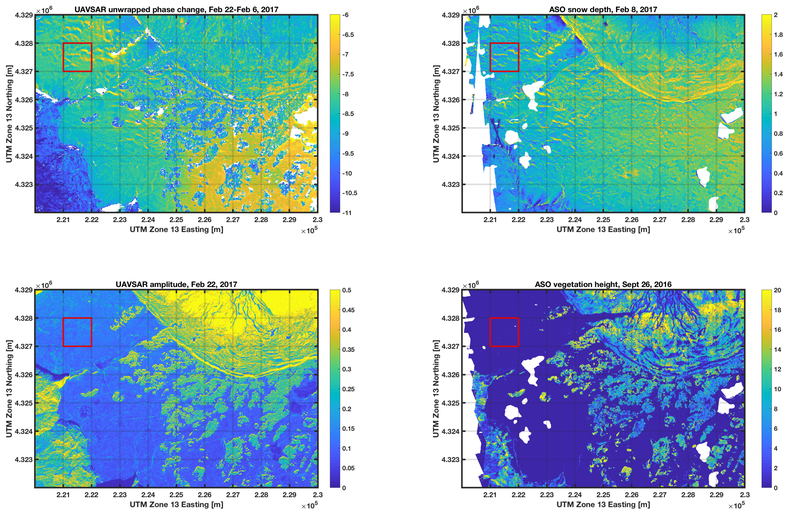

Figure 1: Upper left: InSAR phase change [rad]. Upper right: LiDAR snow depth [m]. Lower left: InSAR amplitude [dB]. Lower right: LiDAR vegetation height [m].

1 km^2 statistical comparison

- Comparison of LiDAR depth and InSAR phase change over 1 km^2 region (red box in Fig. 1)
- Very similar pattern, with phase change and depth highly correlated

- Random forest using InSAR phase, amplitude, coherence, incidence angle
- Out-of-bag RMSE = 11.3 cm, R^2=0.82
- Phase change was by far the most important predictor variable, in agreement with theory

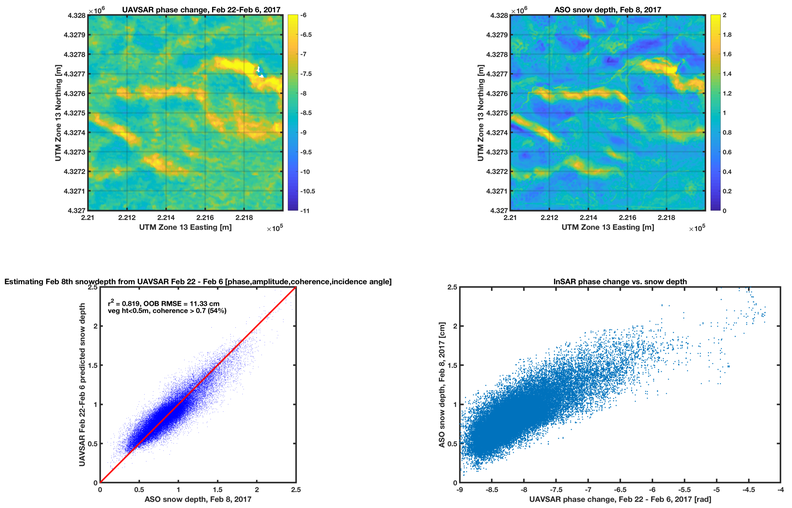

Figure 2: Upper left: InSAR phase change [rad]. Upper right: LiDAR snow depth [m]. Lower left: predicted snow depth from random forest. Lower right: InSAR phase change vs. LiDAR snow. depth

Depth change and total depth, compared to in-situ observations

- LiDAR snow depths agree with in-situ observations with RMSE=10-20cm, as expected from previous studies
- InSAR depth changes from *Guneriussen et al.* (2001):
  $\Delta d = -\frac{\Delta\phi\,\lambda}{4\pi}\,\frac{1}{\cos\alpha - \sqrt{\epsilon_s - \sin^2\alpha}}$
- Field campaign was designed to measure *total SWE* distribution, not changes in SWE
- Comparison with in-situ observations challenged by small total change (10-20 cm) relative to short length scale variation (30-50cm)
- Changes in depth below accuracy of LiDAR, challenging the use of repeat snow-on LiDAR to map depth changes during February 2017

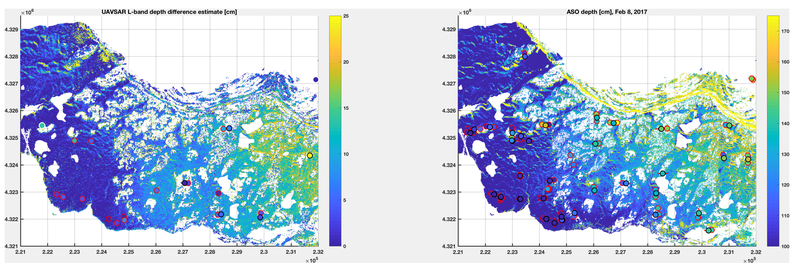

Figure 3: Left: InSAR depth estimate, with in-situ depth changes shown with filled circles. Right: LiDAR snow depth, with in-situ depths shown with filled circles.

InSAR depth change at 1 km^2 scale

- At 1 km^2 scale in open region with large short length scale variability, InSAR depth changes mimic total snow depth pattern
- Over this region, LiDAR depth changes are reasonable, with the exception of a flight line artifact on the right side
- Depth changes from LiDAR and InSAR agree with an RMSE of 6.6 cm over a dynamic range of 25 cm, with a bias-corrected RMSE of 5.0 cm
- These depth changes correspond to SWE changes on the order of 1-4 cm, with an accuracy of less than 1 cm
- Sensitivity to new snowfall at the 1 cm level could be very useful to the snowfall remote sensing community

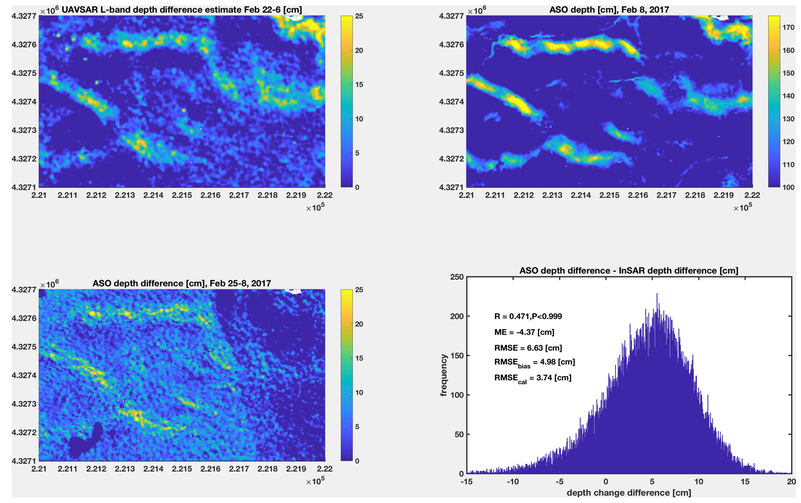

Figure 4: Top left: InSAR depth change retrieval. Top right: LiDAR snow depth. Bottom left: LiDAR depth change. Bottom right: histogram of LiDAR-InSAR depth change.

Acknowledgments

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