Stereo2SWE

On-demand, high-resolution time series of snow depth and SWE from sub-meter stereo satellite imagery

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Summary

- We are evaluating currently available very-high-resolution (~0.3 to ~0.9 m) commercial satellite stereo image resources, and their operational potential for high-resolution maps of snow depth and SWE on a global scale
- We coordinated tasking of DigitalGlobe WorldView-1/2/3 and Planet SkySat-C for snow/ice targets in CONUS/AK. Data for Grand Mesa, SBB and other SnowEx sites available 2016–2019.
- We are developing automated, open-source workflows to generate co-registered time series of digital surface models (DSMs) using NASA Ames Stereo Pipeline and NASA HPC resources.
- DSM time series provide maps of snow depth, and multiple density models are used to estimate SWE. Vertical accuracy is <20-50 cm and we are working with vendors to perform on-orbit calibration, develop sub-pixel image corrections, and refine data collection strategies with the goal of achieving ~10-15 cm DSM accuracy.
- Preliminary comparisons show good agreement between the satellite stereo snow depth products and ASO, in situ GPR, and in situ probe measurements.
- We are developing machine-learning algorithms for landcover classification (e.g., snow, vegetation, bare ground) using contemporaneous ~1.2-1.8 m multispectral (and 3.4 m SWIR) and complementary ~3-5 m PlanetScope (Dove) imagery. These products will enable advanced stereo processing and offer improved regional snow-covered area mapping, without the need for spectral mixture analysis.

Tasking and Archive

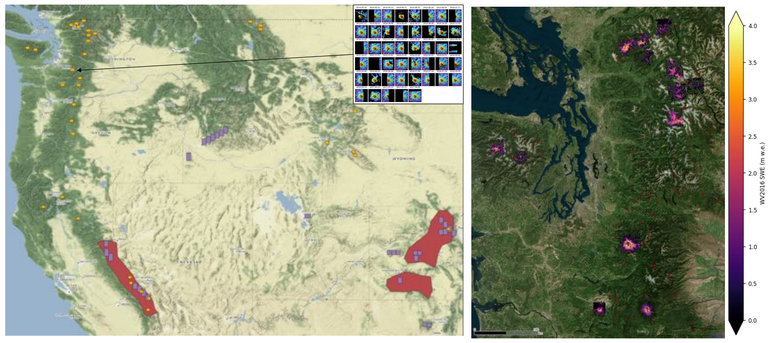

Figure 1: Left) CONUS DigitalGlobe stereo tasking plan for 2019/2020. Purple are SnowEx 2020 sites (~2 week interval), gold are long-term glacier/snow monitoring sites (~2x spring, ~2x summer/fall), red are larger area collect (~1x spring, ~1x summer). Inset shows time series for Mt. rainier from 2014–2017. Right) Map of preliminary WY2016 SWE estimates for WA long-term sites in WA state.

Methodology

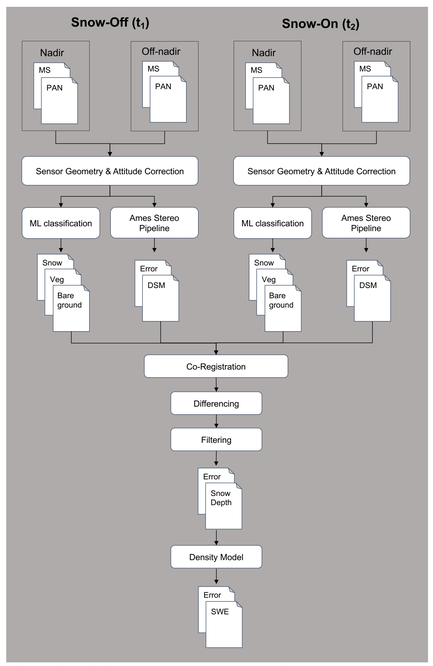

Figure 2: Stereo2SWE Processing workflow for WorldView-2/3.

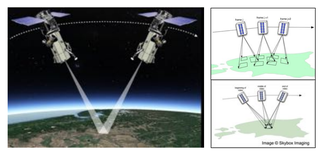

Figure 2: Stereo acquisition for WorldView (left), Skysat triplet stereo collect (top right), and SkySat video stereo (bottom right).

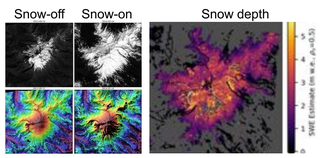

Figure 2: Sample products for Mt. Baker, WY2014.

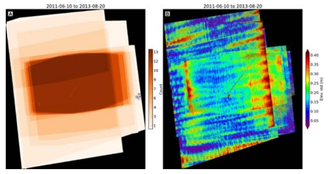

Figure 2: Sample count (left) and per-pixel standard deviation (right) for stack of 14 DSMs over Summit Station, Greenland. The std map provides a sense of relative DSM accuracy, revealing residual sensor geometry and attitude ("jitter") artifacts. We are attempting to correct these (see figures to right).

Preliminary results for SnowEx'17

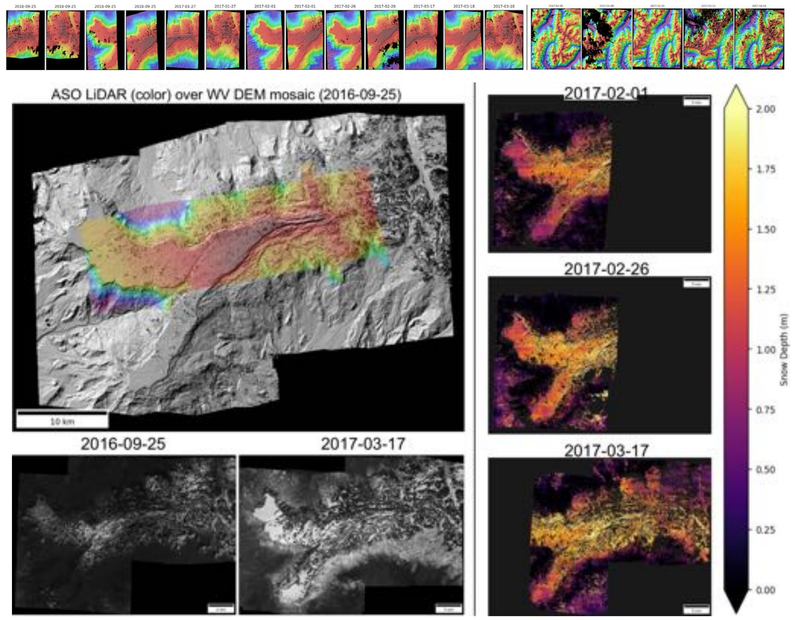

Figure 3: Preliminary Stereo2SWE results for the SnowEx'17. Top left shows ASO snow-off LiDAR (color overlay, ~351 km² @3-m posting) and the larger WV-3 DSM mosaic shaded relief (~1196 km² @2-m posting). Lower left shows TOA reflectance for snow-off and snow-on WV-3 imagery. Right column shows time series of snow depth for WV-3 DSM mosaics..

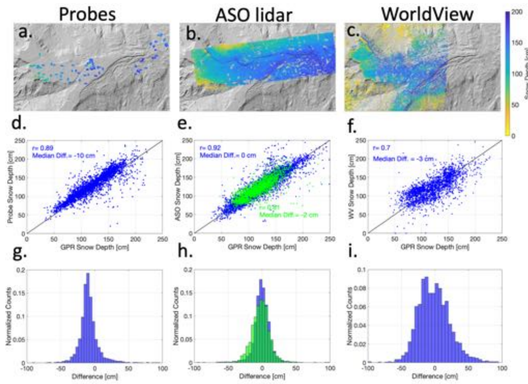

Figure 4 from McGrath et al., WRR, 2019: Snow depth derived from a) manual probes, b) ASO lidar DTMs, and c) Worldview satellite DSMs. Scatterplots of snow depth from d) manual probes, e) ASO lidar DTMs, and f) Worldview satellite DSMs compared to GPR-derived snow depths. Blue points in e and f have ASO-derived canopy heights <2 m, green points have ASO-derived canopy heights >2 m. Histograms of difference between g) GPR-probes, h) GPR-ASO, and i) GPR-WorldView.

WorldView Sensor Corrections

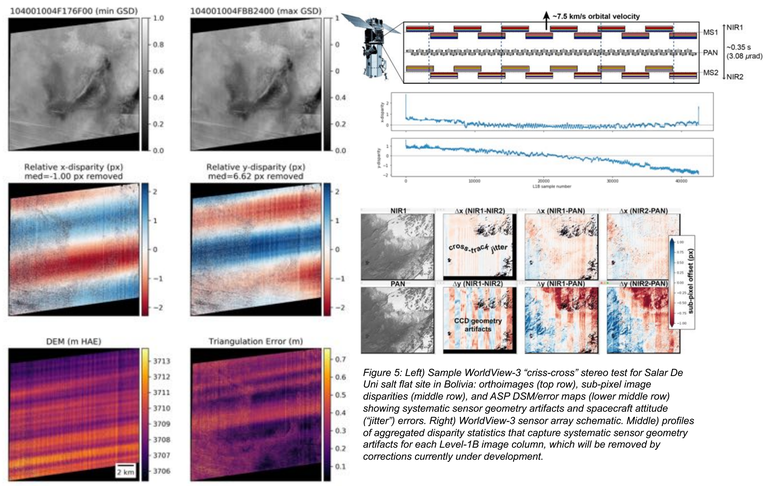

Figure 5: Left) Sample WorldView-3 "criss-cross" stereo test for Salar De Uni salt flat site in Bolivia: orthoimages (top row), sub-pixel image disparities (middle row), and ASP DSM/error maps (lower middle row) showing systematic sensor geometry artifacts and spacecraft attitude ("jitter") errors. Right) WorldView-3 sensor array schematic. Middle) profiles of aggregated disparity statistics that capture systematic sensor geometry artifacts for each Level-1B image column, which will be removed by corrections currently under development.

Planet SkySat Triplet Stereo

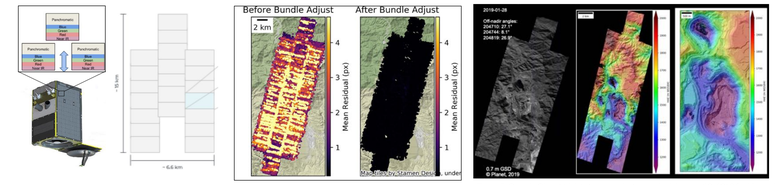

Figure 6: Left) SkySat-C model with 3 PAN/MS detectors focal plane layout. Middle) SkySat-C mono image collect layout, with ~50-60 scenes from the 3 detectors. Right) Residuals for feature matches between all ~300 scenes from two triplet stereo samples, before correction (left) and after correction (right). This step improves relative DSM accuracy.

Figure 7: Sample Skysat triplet stereo products acquired January 28, 2019 for Morenci Mine site in Arizona a) Orthoimage, b) Composite 4-m ASP DSM produced from two triplet stereo collections (6 images total), c) Detail of steep slopes in open pit.

Planet SkySat Video Multi-View Stereo

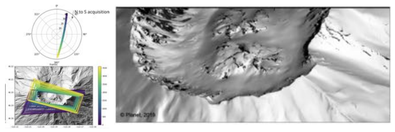

Figure 8: Left) SkySat video acquisition geometry and footprints for frames 0-3600 of Mt. St. Helen's sample. Right) Video frame near the end of the video sequence with high off-nadir acquisition geometry.

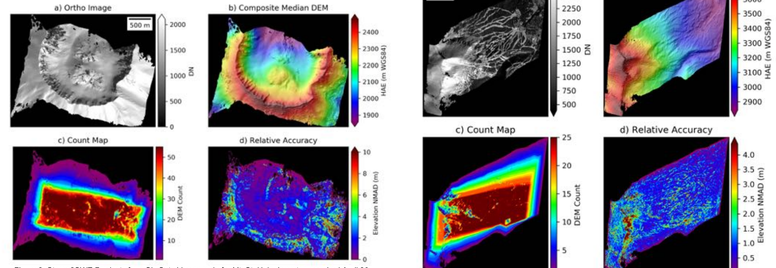

Figure 9: Stereo2SWE Products from SkySat video sample for Mt. St. Helen's crater, acquired April 20, 2019 (near peak SWE): a) Orthorectified image mosaic, b) Composite ASP DSM from 55 stereo pairs, c) per-pixel DSM count, and d) per-pixel Normalized Mean Absolute Difference (NMAD), which provides metric for relative accuracy of composite DSM. Note DSM quality over steep crater wall slopes and <1 m relative accuracy over crater floor.

Figure 10: Sample skysat video products from November 7, 2018 for Breckenridge, CO. See Figure 9 caption for details. Note excellent retrievals over snow and between stands of trees.

Snow cover classification

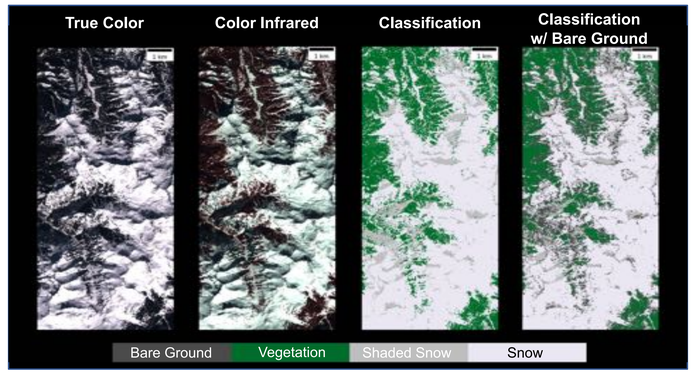

Figure 11: a) Sample portion of February 17, 2018 WorldView-3 image over CO and preliminary 1.2 m classification maps.

Summary of Available Sensors

Platform	Coverage for single collection (km²)	Image Resolution (m)	Image bands	Number of multi-view stereo images	DSM Relative Vertical Accuracy* (m) *for surface slope <10°	Tasking capabilities for repeat or on-DSMand coverage	Cost (0 = existing federal or research access)
DigitalGlobe WorldView-1/2/3	170-1870	0.3-0.5 1.2 3.4	Panchromatic 8-band MS SWIR option	2	<0.5	Fair-Good	0
Planet SkySat video	2-4	1.0	Panchromatic	900-3600	<0.5-1.0	Good	$$$$
Planet Skysat triplet stereo	60-70	0.7 1.0	Panchromatic 4-band MS	3	<1-3, TBD	Good	$$
Planet PlanetScope (Dove)	400 (spatially continuous)	3-4	4-band MS	2-9+	>3 m, TBD	Temporally continuous	0/$