ICESat-2 for Forestry Applications

Amy Neuenschwander[1]
[1]University of Texas at Austin, Austin, TX 78701
Email: amy@csr.utexas.edu

1. Introduction

On September 15, 2018 NASA launched the ICESat-2 (Ice, Cloud, and land Elevation Satellite-2) laser altimeter from Vandenburg Air Force Base. Although the primary mission goal of ICESat-2 is to monitor changes in the cryosphere, ICESat-2 also collects elevation data over the Earth's land surfaces providing geodetic measurements to support a wide range of terrestrial applications. In the temperate and tropical regions, ranging measurements from ICESat-2 are used to produce estimates of terrain and canopy heights of the worlds' forests. The density and vertical distribution of the returned photons from within the canopy can be utilized to infer information regarding forest biomass, canopy volume, habitat mapping, biodiversity, and parameterization of land-climate models. The ICESat-2 satellite is in a polar orbit (92 degrees) and is the only space based laser altimeter capable of collecting ranging measurements over all land surfaces.

The instrument onboard ICESat-2 is the Advanced Topographic Laser Altimeter System (ATLAS) and ATLAS is sensitive to detect single photons reflected from the surface. ATLAS uses a 532 nm laser that fires at a rate of 10 kHz (or every 70 cm on the Earth's surface) which facilitates high spatial resolution in the along-track direction. A diffractive optical element splits the ATLAS laser into 6 beams; 3 beam pairs approximately 3 km apart. Each beam pair is comprised of a strong beam and weak beam. Because ATLAS is sensitive at the photon level, solar background noise can present a challenge in the analysis or photon counting data. ICESat-2 is a profiling lidar and a result of the beam configuration is high resolution in the along-track direction; however gaps exist between beams. In the mid-latitudes, ICESat-2 operates in vegetation mode which consists of off-nadir pointing the satellite to a different ground track each 91-day repeat cycle. Thus, rather than repeating an orbit every 91 days, ICESat-2 will point to a different location on the Earth to improve the spatial sampling. Over a period of two years, this series of off-pointing maneuvers has reduced the distance between tracks at the equator from 29 km to approximately 2 km. As the mission continues through time with more off-pointing maneuvers, the distance between ground tracks will continue to decrease.

1.1 Land and Vegetation Data Product (ATL08)

Because ATLAS is a photon counting system operating at a much lower energy that typical waveform or discrete return lidar systems, only a handful of photons (~1 – 2) are returned from each outgoing laser pulse. The actual number of returned photons is a function of the surface reflectance and vary over different forest types. As such, determination of the surface (both ground and top of canopy) requires the accumulation of photons across a larger distance. Because the detectors on ATLAS are sensitive at the photon level, they will also detect solar background photons both above and below the reflected signal photons. The algorithm utilized to create the Land and Vegetation Data Product (ATL08) uses a series of cluster/density filters to eliminate background noise and iterative filters to identify the ground and top of canopy surfaces. The ATL08 algorithm then labels each photon as ground, canopy, top of canopy, or noise and subsequently reports statistics for both the ground and canopy for a 100 m step size along the orbit direction.

Published in: Markus Hollaus, Norbert Pfeifer (Eds.): Proceedings of the SilviLaser Conference 2021, Vienna, Austria, 28–30 September 2021.
Technische Universität Wien, 2021. DOI: 10.34726/wim.1861
DOI of this paper: 10.34726/wim.2031

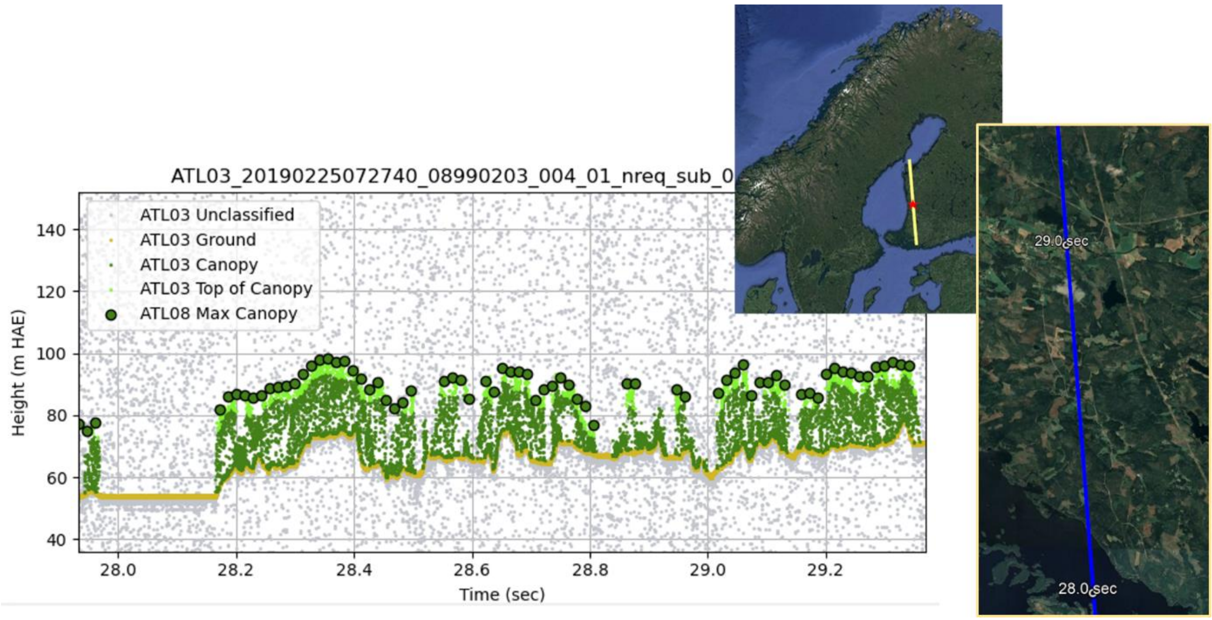

Figure 1: Transect of ICESat-2 data over Western Finland. The individual photons available on the ATL03 data product are color coded with the assigned label (ground, canopy, top of canopy, or noise) from the ATL08 algorithm. The large green dots correspond to the ATL08 canopy height value reported every 100 m in the along-track direction.

2 Results of Canopy Height Estimates

Figure 2 illustrates the ATL08 canopy height errors plotted against canopy cover for managed forests in Southern Finland (Neuenschwander et al. 2020). The mean absolute errors for each stratification scenario show that the ATL08 canopy height errors improved as canopy cover increased from 10–40%. The MAE plateau from 40–80% and then gradually increase above 80%. These results, combined with the results from the terrain residuals indicate that at low canopy cover (<40%) where the terrain estimates are more accurate, ICESat-2 likely does not capture enough canopy reflections to obtain an accurate estimate of a canopy height. Canopy heights are most accurate in the 40-80% range of canopy cover, with dense cover (>80%) associated with increasing errors when there are likely less ground photons being reflected and detected.

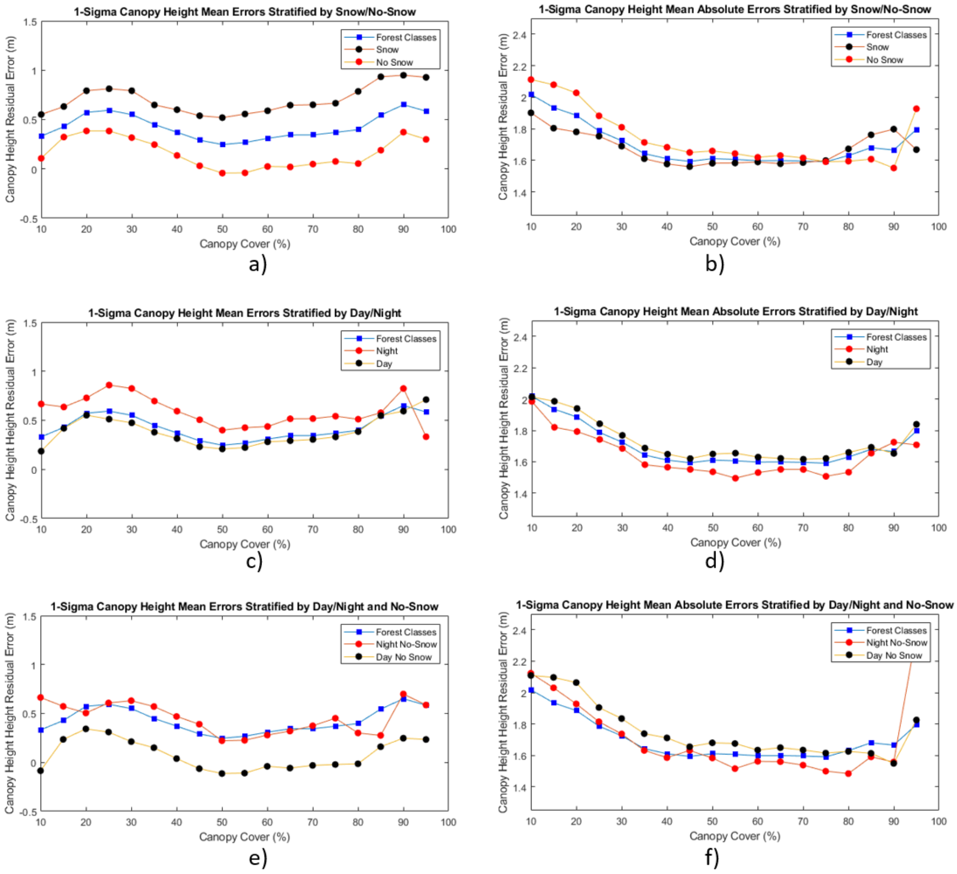

Figure 2. Canopy height residuals of ATL08 strong beam 1-sigma plotted against canopy cover a) mean errors stratified by snow/no-snow b) mean absolute errors stratified by snow/no-snow c) mean errors stratified by day/night d) mean absolute errors stratified by day/night conditions e) mean errors stratified by day/night for no-snow conditions and f) mean absolute errors stratified by day/night for no-snow conditions. (From Neuenschwander et al. 2020)

Results from this study indicate that the strong beam consistently provided better canopy height estimates than the weak beam. For forested classes, canopy height retrievals during the summer months at night yielded the lowest errors with a mean bias of 0.56 m and a RMSE% of 13.75% which is in line with canopy height retrievals from lidar estimates of forest canopies (Næsset, 1997; Magnussen and Boudewyn 1998, Næsset and Økland 2002, Næsset 2007). Much of the success of the canopy height retrievals in the Neuenschwander (2020) Finland study are based on the ability to accurately determine the underlying terrain. In other regions where atmospheric conditions or vegetation cover limits the detection of the ground surface, canopy height estimates will certainly be less accurate. We found that ATLAS data acquired during the summer months (May–August) had the lowest canopy height errors (mean ~0.5 m, RMSE ~2.5 m, %RMSE ~14.5%). In snow conditions, the canopy height errors are larger (mean ~1.1 m, RMSE ~2.7 m, %RMSE ~16.3%), however, these larger errors are likely the result of seasonal differences between ICESat-2 and the airborne lidar data used as reference, as well as snow-covered terrain biasing the relative canopy heights.

Although ICESat-2 was not specifically designed for canopy height retrievals, it has shown to provide useful canopy height estimates for global observations, particularly at latitudes where GEDI does not collect data.

Acknowledgements

This work is funded through the NASA Cryospheric Office for the ICESat-2 Science Team grant (NNH19ZDA001N-ICESAT2) and NASA's Terrestrial Ecology program Arctic Vulnerability Experiment (ABoVE) grant (NNH18ZDA001N-TE).

References

Næsset, E. 1997. "Determination of mean tree height of forest stands using airborne laser scanner data." ISPRS *Journal of Photogrammetry & Remote Sensing*, Vol. 52: pp. 49–56.

Næsset, E., and Økland, T. 2002. "Estimating tree height and tree crown properties using airborne scanning laser in a boreal nature reserve." *Remote Sensing of Environment*, Vol. 79: pp. 105–115.

Næsset, E. 2007. "Airborne laser scanning as a method in operational forest inventory: status of accuracy assessments accomplished in Scandinavia." *Scandinavian Journal of Forest Research*, Vol. 22: pp. 433–442.

Neuenschwander, A. and Pitts, K., 2019. The ATL08 land and vegetation product for the ICESat-2 Mission. *Remote Sensing of Environment*, 221: 247-259. [doi: 10.1016/j.rse.2018.11.005]

Neuenschwander, A., Guenther, E., White, J., Duncanson, L., and Montesano, P. 2020 Validation of ICESat-2 terrain and canopy heights in boreal forests. *Remote Sensing of Environment*, 251. https://doi.org/10.1016/j.rse.2020.112110