Prediction of height, basal-area and stem volume in boreal forest using Pléiades or WorldView-2 acquisitions

Henrik J. Persson[1*], Håkan Olsson[1], Johan E.S. Fransson[1]

[1]Department of Forest Resource Management, Swedish University of Agricultural Sciences, Umeå, Sweden

*Corresponding author: henrik.persson@slu.se

Abstract

This paper evaluates predictions of Lorey's mean height (H_L), basal-area (BA) and stem volume (VOL) of boreal forest at two Swedish test sites, Krycklan and Remningstorp. Forest heights derived from very high resolution stereo matched satellite data from the Pléiades sensor or the WorldView-2 sensor were trained with 10 m field plots and then predictions and evaluations were performed on independently inventoried 40 m field plots. The best prediction results were found in Krycklan with WorldView-2 data, with H_L = 3.4% RMSE, VOL = 9.8% RMSE and BA with 9.7% RMSE. In conclusion, both sensors delivered robust and accurate imagery for both the evaluated test sites. Moreover, the presented approach appears suitable for operational forestry planning, especially at remote locations with limited or no other remote sensing data.

Keywords: stereo, satellite, forest, WorldView, Pléiades

Introduction

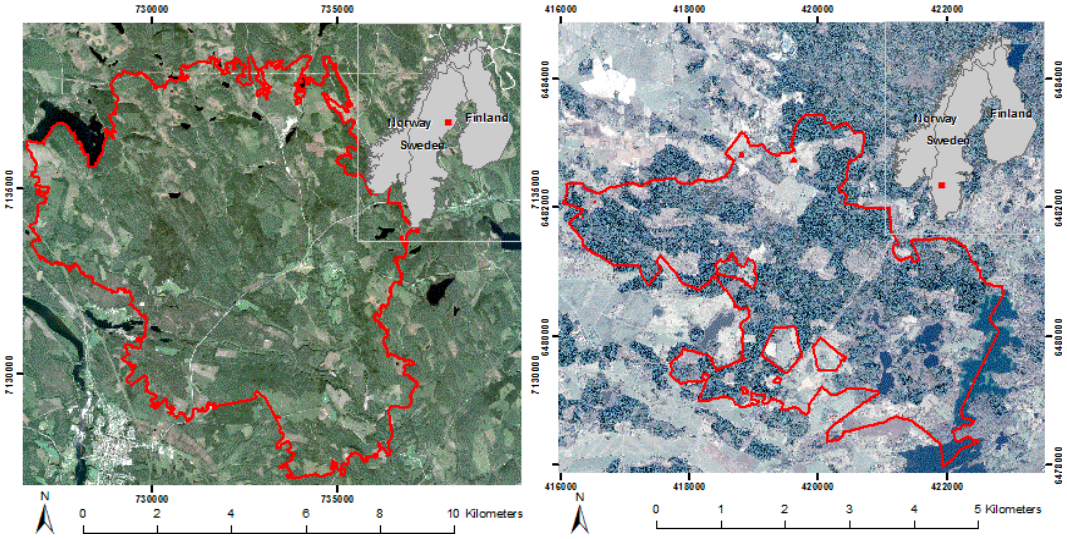
There is a steady need of establishing and updating information about the forest. Airborne laser scanning (ALS) has for more than one decade been considered the most accurate remote sensing technique that in combination with field samples can be used to create wall-to-wall estimations of typical forest variables, like Lorey's mean height (H_L), stem volume (VOL) or basal-area (BA). Many countries, including Sweden, can now offer complete national terrain models based on ALS, which has enabled also other techniques for estimations of this type of variables. One such technique uses images acquired from at least two directions which enables stereogrammetric image matching to derive heights. For this purpose, aerial images or very high resolution (VHR) satellite images are suitable, as they often possess resolutions below one meter. The image matched result is a digital surface model (DSM) from which the terrain model can be subtracted to obtain the forest canopy height, which can be correlated with different forest variables. One main advantage of using stereo matched VHR images over ALS data, is the significant lower price ($40/km^2 compared to >$200/km^2), and the high repetition frequency of the satellites passing the region of interest (often within days or a few weeks). The VHR imagery have hence appeared as an attractive option to the more expensive ALS data. The stereo matched heights have been investigated in a number of papers, but very few have compared the sensors Pléiades and WorldView-2, both with image ground sampling distances of about 0.5 m, in boreal forest (Persson & Perko 2016; Persson 2016; Immitzer et al. 2016; Yu et al. 2015; Shamsoddini et al. 2013).

This work evaluates and compares the estimation of the forest variables Lorey's mean height, stem volume and basal-area, using stereogrammetrically matched VHR imagery from the Pléiades or WorldView-2 sensors.

Methods

VHR imagery have been stereogrammetrically matched, using the software Remote Sensing Package Graz, which utilizes the semi-global matching algorithm, to derive height rasters. The processing is further described in (Persson & Perko 2016; Persson 2016). The terrain height (obtained from a national laser scanning for the duration of 2009 to 2016) was subtracted to obtain canopy heights. From the derived height rasters, different metrics, e.g., mean height, standard deviation, and numerous height percentiles, were extracted for field plots located on the two test sites. These metrics were furthermore used as explanatory variables in multiple linear regression models, where the models were trained on plots with 10 m radius, and hereafter the models were evaluated on independently inventoried 40 m plots.

The performance of respective VHR sensor was evaluated and compared at two Swedish test sites illustrated in Figure 1 (Krycklan, Lat. 64°16'N, Long. 19°46'E, and Remningstorp, Lat. 58°30'N, Long. 13°40'E). Systematic 10 m field plots were distributed at the respective test sites, from which the field variables in question have been computed, using established allometric equations. The estimated variables were H_L, BA and VOL. In Krycklan, the five hundred 10 m plots were inventoried during the fall 2015, while the thirty-two 40 m plots were inventoried primarily before the 2016 vegetation season. In Remningstorp, both the two hundred sixty 10 m plots and the forty 40 m plots were inventoried during the fall 2014. At all inventoried plots, only trees with diameter breast height ≥0.04 m were calipered. Both the Pléiades and WV2 data were acquired during 2015.



(a) **(b)**

Figure 1. Ortho-rectified Pléiades images of the two test sites superimposed in red. Krycklan (a) and Remningstorp (b), located in northern (64°N) and southern (58°N) Sweden, respectively, projected in the UTM 33N coordinate system on the WGS84 reference ellipsoid. ©CNES_2015, distribution Astrium Services / Spot Image S.A, France, all rights reserved

Results

From inspection of the model coefficients and extracted heights, it appears that most WV2 height percentiles are similar to each other, located close to the top height, while the Pleiades height percentiles differ more. That is, the Pléiades sensor appears to catch a larger dynamic range compared to the WV2 sensor. Moreover, the detected top height appears generally higher for the WV2 sensor compared to the Pleiades. However, this might be due to possible differences on how the acquired bands are used in the matching. The WV2 images used in this study were acquired as panchromatic images at 450-800 nm, while the Pléiades images were acquired in four spectral bands, blue, green, red, and near-infrared, with the possible (but not used) panchromatic range of 480-830 nm, and possibly only a single band was used in the image matching, which might cause the larger height differences. This is to be clarified.

Estimation results from both sensors at the two test sites indicate robust and similar results at both test sites, despite the differences in the forests. The heights were estimated with an RMSE below one meter in Krycklan, corresponding to 3% to 6% RMSE, while the accuracy was almost identical in Remningstorp, with 5% RMSE (Table 1). As height was the only variable directly derived from the VHR imagery, the same source of explanatory variables (sometimes in transformed forms) were used to predict H_L, VOL and BA. Therefore, the similarity in the height results is reflected also for the variables VOL and BA, with almost identical results for respective sensor, at the respective test site. However, the across test site values differ slightly, which might be due to several reasons, including sampling errors, differences in time for the image acquisitions and the field samples, and moreover due to the differences of the forest types. One observation was that the estimation accuracy of basal-area and stem volume was highly correlated, despite that stem volume is considered a three-

dimensional unity (including both height and density of the forest) while basal-area often functions as one measure of forest density.

The scatter plots were similar between the variables and sensors, and hence an example on scatter plots of the H_L, VOL and BA estimated from Pléiades are illustrated in Figure 2 a,c,d and in addition, the height estimation from WV2 data is also included (Figure 2 b) for comparison.

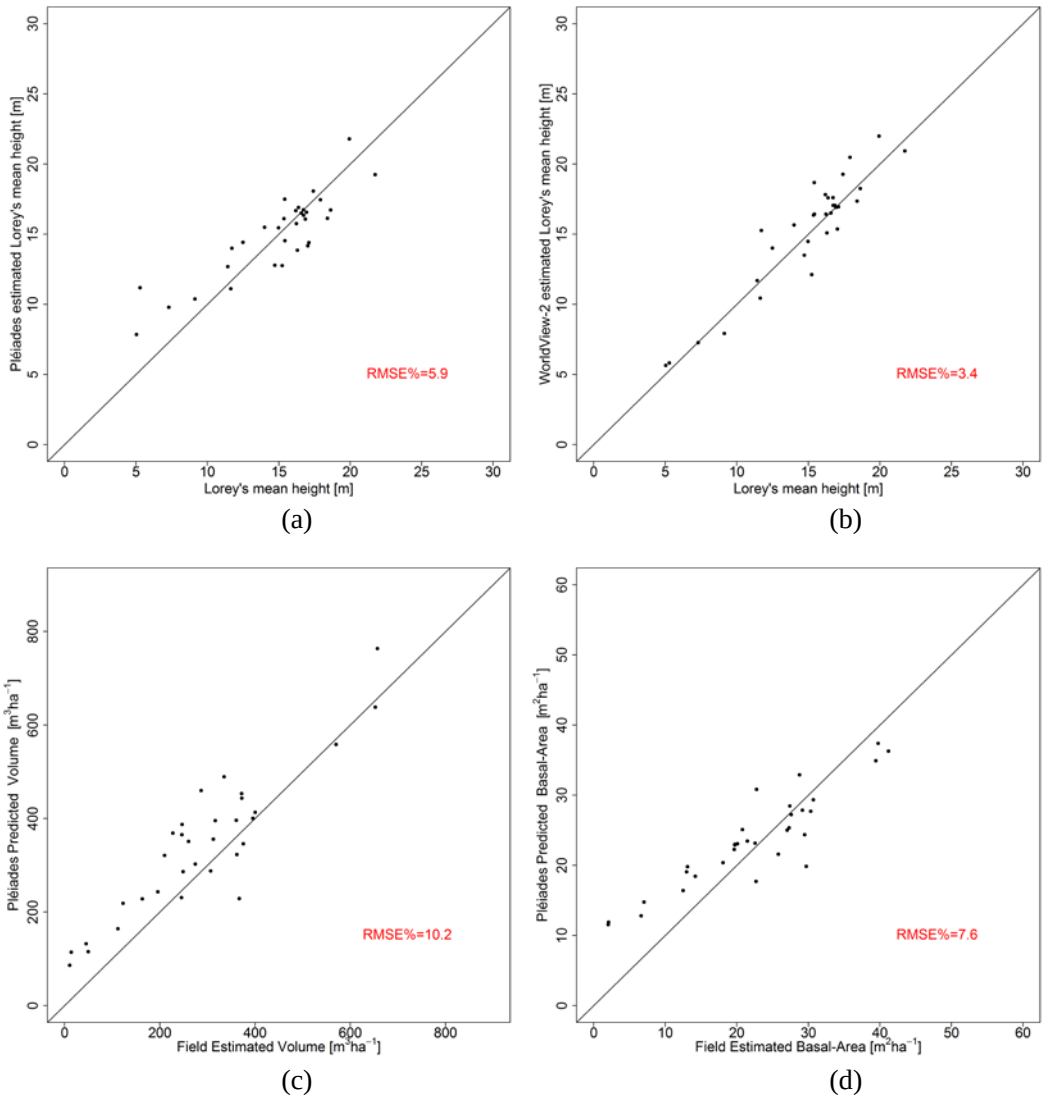


Figure 2. Scatter plots of the evaluated predictions from the Krycklan test site. a,c,d are estimations with the Pléiades sensor and b from the WV2 sensor. a) H_L, b) H_L, c) VOL, d) BA

Table 1 –Results from evaluation of the independently inventoried plots with 40 m radius.

Test site	Sensor	Variable	Unit	RMSE	RMSE%
Krycklan	Pléiades	H_L	m	0.876	5.88
Krycklan	Pléiades	VOL	m^3/ha	29.1	10.2
Krycklan	Pléiades	BA	m^2/m^2	1.69	7.61
Krycklan	WorldView-2	H_L	m	0.502	3.38
Krycklan	WorldView-2	VOL	m^3/ha	27.9	9.80
Krycklan	WorldView-2	BA	m^2/m^2	1.51	9.67
Remningstorp	Pléiades	H_L	m	1.09	4.84
Remningstorp	Pléiades	VOL	m^3/ha	36.1	10.9
Remningstorp	Pléiades	BA	m^2/m^2	3.06	10.1
Remningstorp	WorldView-2	H_L	m	1.10	4.88
Remningstorp	WorldView-2	VOL	m^3/ha	38.4	11.6
Remningstorp	WorldView-2	BA	m^2/m^2	3.41	11.2

Conclusions

The conclusion is that stereo matching of VHR satellite images is a promising method for estimating forest variables, when a high-resolution terrain model is available. The results from this study, indicated that the dynamic range of Pléiades heights is larger than the heights obtained fromWV2 data. The BA and the VOL were highly correlated, considering prediction accuracy, and both sensors are giving robust and accurate acquisitions at both the evaluated test sites.

Acknowledgments

The authors would like to thank the AdvancedSAR FP 7 project under Grant 606971 for financial support and to enable access to WorldView-2 imagery. The Swedish National Space Board is acknowledged for providing the Pléiades images. This work has also received funding from the Hildur and Sven Wingquist foundation.

References

Immitzer, M. et al., 2016. Forest Ecology and Management Use of WorldView-2 stereo imagery and National Forest Inventory data for wall-to-wall mapping of growing stock. *Forest Ecology and Management*, 359, pp.232–246. Available at: http://dx.doi.org/10.1016/j.foreco.2015.10.018.

Persson, H., 2016. Estimation of Boreal Forest Attributes from Very High Resolution Pléiades Data. *Remote Sensing*, 8(9), p.736. Available at: http://www.mdpi.com/2072-4292/8/9/736/ [Accessed September 6, 2016].

Persson, H.J. & Perko, R., 2016. Assessment of boreal forest height from WorldView-2 satellite stereo images. *Remote Sensing Letters*, 7(12), pp.1150–1159. Available at: https://www.tandfonline.com/doi/full/10.1080/2150704X.2016.1219424.

Shamsoddini, A., Trinder, J.C. & Turner, R., 2013. Pine plantation structure mapping using WorldView-2 multispectral image. *International Journal of Remote Sensing*, 34(11), pp.3986–4007. Available at: <Go to ISI>://WOS:000315384500016.

Yu, X. et al., 2015. Comparison of laser and stereo optical, SAR and InSAR point clouds from air- and space-borne sources in the retrieval of forest inventory attributes. *Remote Sensing*, 7(12), pp.15933–15954.