Estimating the Site Index using height increments observed from Areal Images or Satellite

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October 31, 2023

Abstract

The productivity of forests is typical expressed with a Site Index giving the height of selected trees at a specific age, e. g. the average height of the 100 highest trees per hectare at the age of 100 years. If the height development over age is known, the site index can be estimated using age and height or height and height increment. Maps giving repeated height measurements could be used to create maps showing the site index. We compare site indices calculated using heights from areal images and heights from satellite with those estimated using a site specific model. To get reliable site indices the height increments need to be observed with high accuracy. Low precision could be handled by aggregating some surrounding pixels.

Tree heights can be observed for large areas up to global scale from areal images or Satellites. The used methods are different. Areal triangulation of a series of areal images (Photogrammetry) or airborne or Satellite laser scanners could be used to get tree heights.

At the Austrian Research Centre for Forests (Bfw) tree heights are calculated for Austria using areal images. For the region of Osttirol we have tree heights for the years 2015, 2018 and 2021 at a spatial resolution of 1 m. Those heights are given in float precision. Potapov u. a. (2022) give global maps of tree heights for the years 2000 and 2020 (Glad). Those maps have a spacial resolution of 0.9 arc seconds (30 m) and give heights in meters. Lang u. a. (2023) give a global map of tree heights for the year 2020 (Eth). This map has a spacial resolution of 0.3 arc seconds (10 m) and give heights in meters.

Figure 1 shows an areal picture of the region at 46.7788 N, 12.8847 E and fig. 2 and 3 gives the heights for the years 2015 and 2021.

Figure 1: Areal Image at 46.779 N, 12.885 E

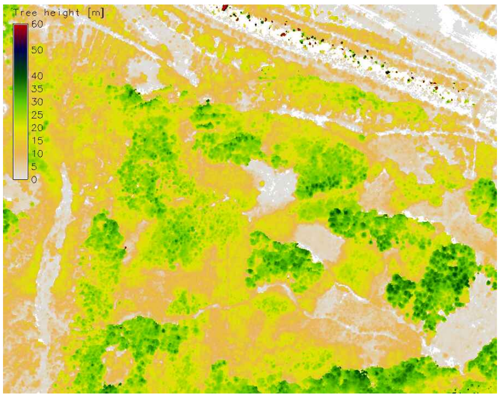


Figure 2: Height in 2015 from BFW

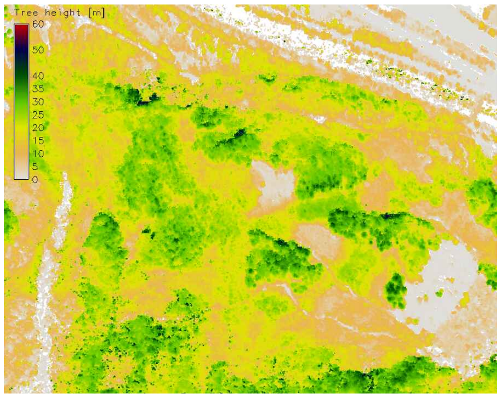


Figure 3: Height in 2021 from BFW

At a resolution of 1 m the crowns of lager trees could be seen on the canopy height images. It is possible to calculate height differences at this resolution and it is also possible to use height with height increment to get a site index. But typical site index is defined using the height of the tip of the tree and not using heights somewhere else on the crown. Figure 4 give the height differences and fig. 5 the site index at 1 m resolution using the site index function from Kindermann (2021).

So those canopy heights need to be aggregated to a lower resolution. As the site index could be defined as the median of the 100 highest trees per hectare a spatial resolution of 10×10 m would contain one of those highest trees. Taking the highest height in this 10×10 m square would be straight forward to get the top height. But the heights have some random variation around the real value and so the 90 qantile was used. Differences between q90 and average, median and maximum are shown in fig. 6.

From those 10×10 m quantiles for specific years the differences could be calculated and with this again the site index could be estimated (fig. 7).

Still it looks like that there is much randomness present. So those site indices on 10×10 m are aggregate by building the median for 30×30 m and 90×90 m (Fig. 8). Reducing the resolution reduces jitter, but still there are regions with implausible high site indices what could be caused by measurement errors.

Beside using the years 2015 and 2021 we have the possibility to estimate the site index by using the years 2015 and 2018 or 2018 and 2021 (Fig. 9). Old trees have only small height increments. For old forests the signal to noise ratio might be poor compared to young forests, which show larger height increments. As the age is not known, those trees with a starting height of >= 3 m and <= 15 m are selected and only for those the site index is estimated (Fig. 9). But it looks like that when taking the single short period of three years increases the signal to noise ratio by reducing the observation time to the half and by selecting only young forests reduces the number of observations and does not lead to a better result.

Beside the tree heights from BFW the Glad heights for the years 2000 and 2020 and the Eth heights for the year 2020 are available (Fig. 11). We compare them for the region of Osttirol (Fig. 10). In a visual comparison the pictures of the heights of BFW and Glad look similar and those from Eth show higher heights. The map of Eth shows tree heights of 10 m in regions where there are definitely no trees. The Glad map shows no heights of 1 m or 2 m. The correlation between the heights of BFW 2021 and Glad 2020 is 0.20,

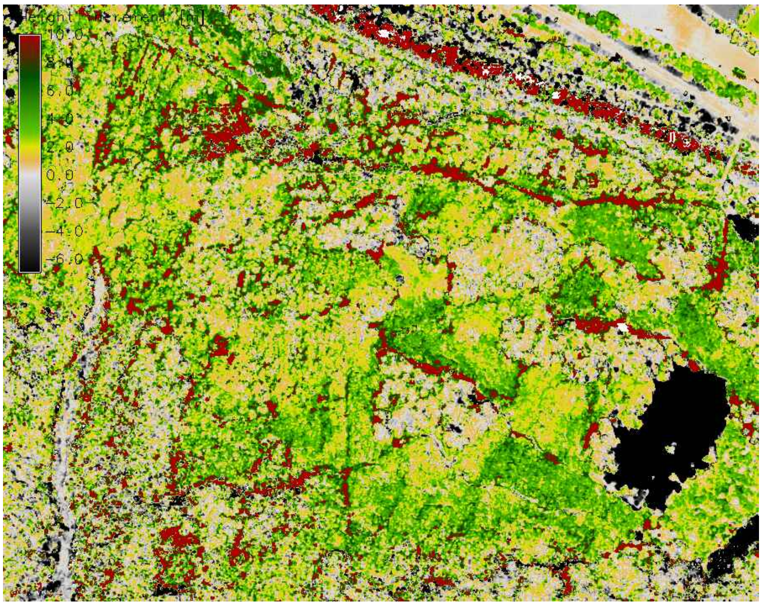


Figure 4: BFW height difference year 2021-2015

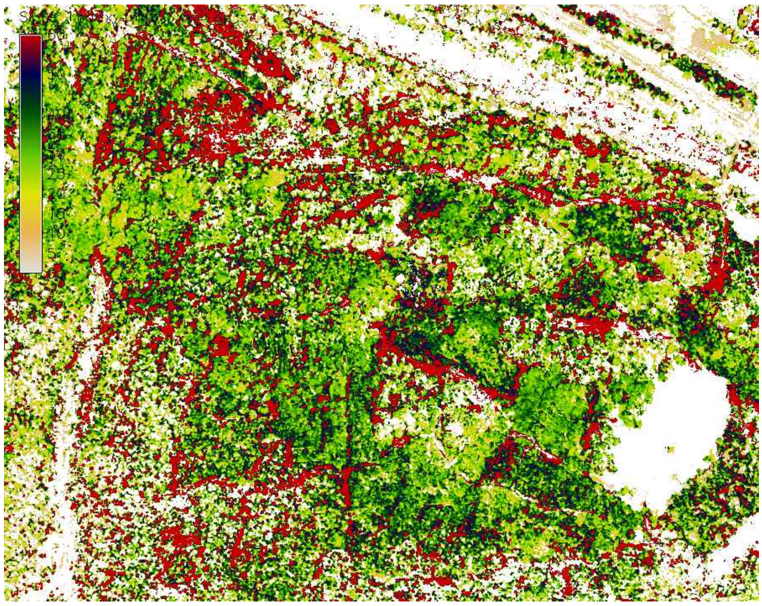
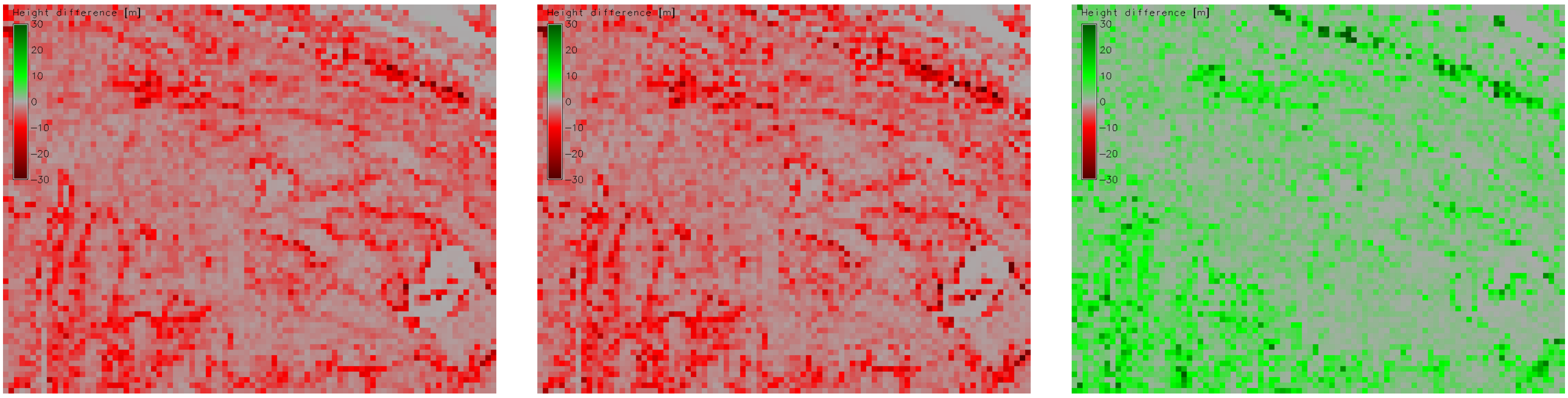
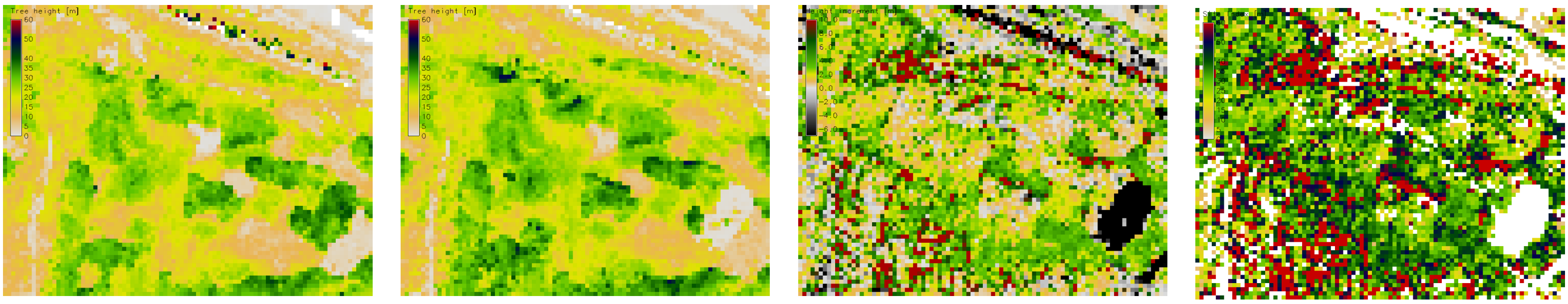


Figure 5: Site Index BFW 2021-2015



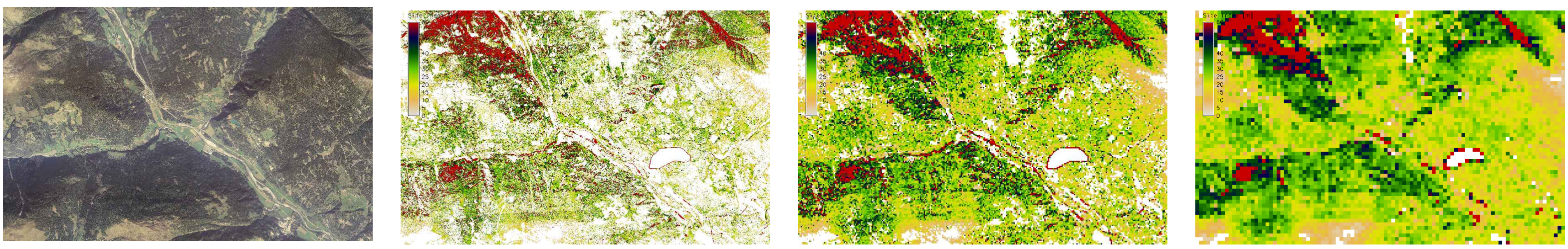
Average - q90 | Median - q90 | Max - q90

Figure 6: Height differences for different way to aggregate to 10×10 m



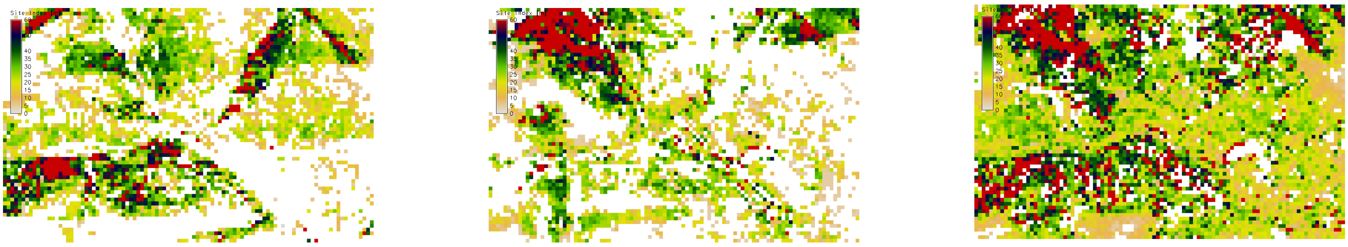
Height q90 2015 | Height q90 2021 | Height difference 2021-2015 | Site Index 2021-2015

Figure 7: Getting site index using q90 at 10×10 m resolution



Areal image | Siteindex 10 m | Siteindex 30 m | Siteindex 90 m

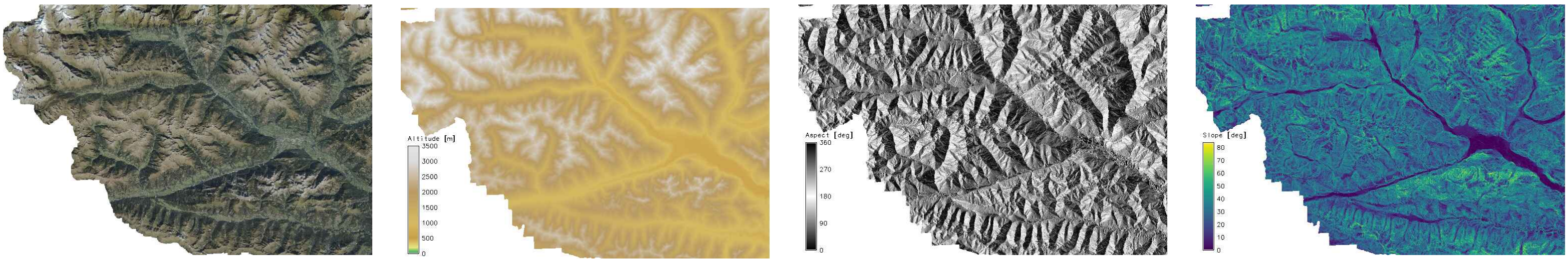
Figure 8: Site index for resolutions of 10×10 m, 30×30 m and 90×90 m for the region around Huben using heights for the years 2015 and 2021



2015 - 2018 | 2018 - 2021 | Young 2015 - 2021

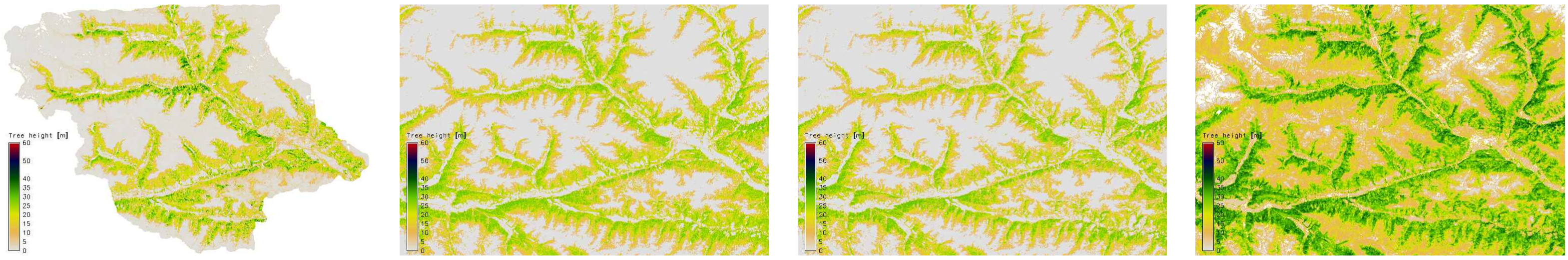
Figure 9: Site index for resolution 90×90 m for the region around Huben using heights for the years 2015 and 2018, 2018 and 2021 and Young forests for 2015 and 2021

between BFW 2021 and Eth 2020 is 0.44 and between Glad 2020 and Eth 2020 is 0.39. The average height of BFW 2021 is 10.7 m of Glad 2020 is 8.4 m and of Eth is 22.4 m. The standard deviation between the heights of BFW 2021 and Glad 2020 is 8.8 m between BFW 2021 and Eth 2020 is 7.5 m and between Glad 2020 and Eth 2020 is 5.9 m. The scatter plots are given in figure 12. The global canopy heights look like to have great potential to provide accurate tree heights, but might need to be bias corrected. The biggest disadvantage for estimating site index is that those global heights are only given in steps of 1 meter. Even if the accuracy is only in the range of 1 m, it still might help, for the purpose of estimating site index, if they are given in dm or cm as the deviation can be reduced by aggregation some pixels like it was done for the heights of BFW. On the other hand the time range of 20 Years is an advantage, as in this time range the height increment will be larger than in 6 or 3 Years.



Areal image | Altitude | Aspect | Slope

Figure 10: Region of Osttirol

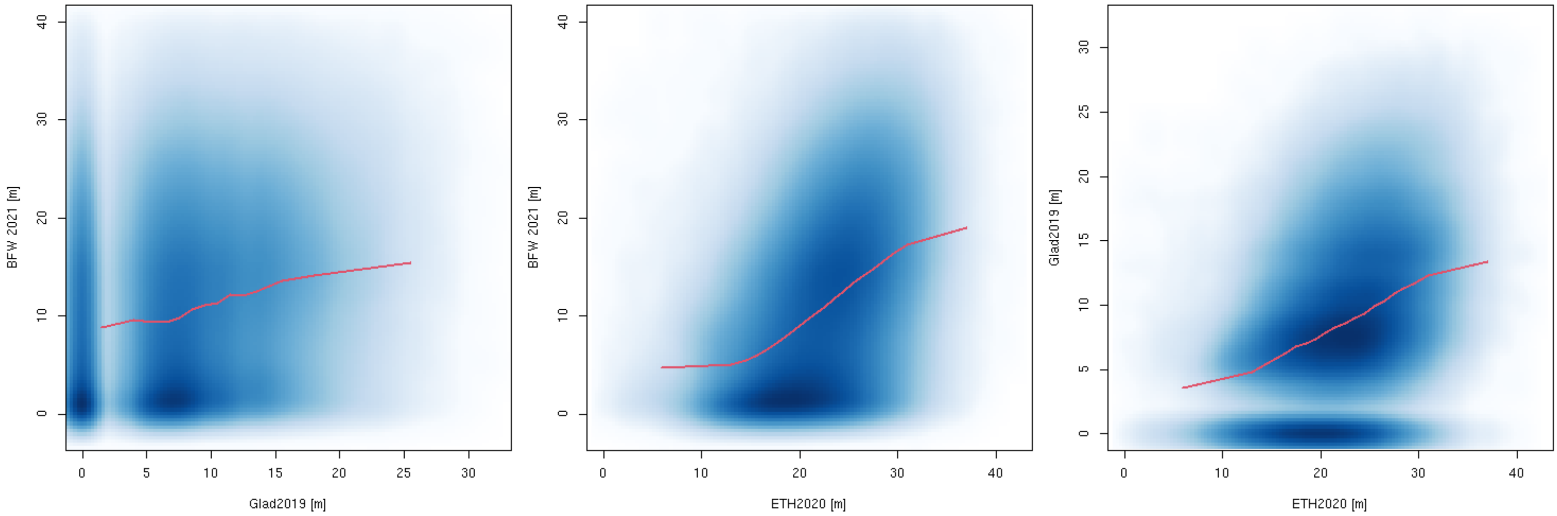


BFW 2021 | Glad 2000 | Glad 2020 | Eth 2020

Figure 11: Different sources for tree height

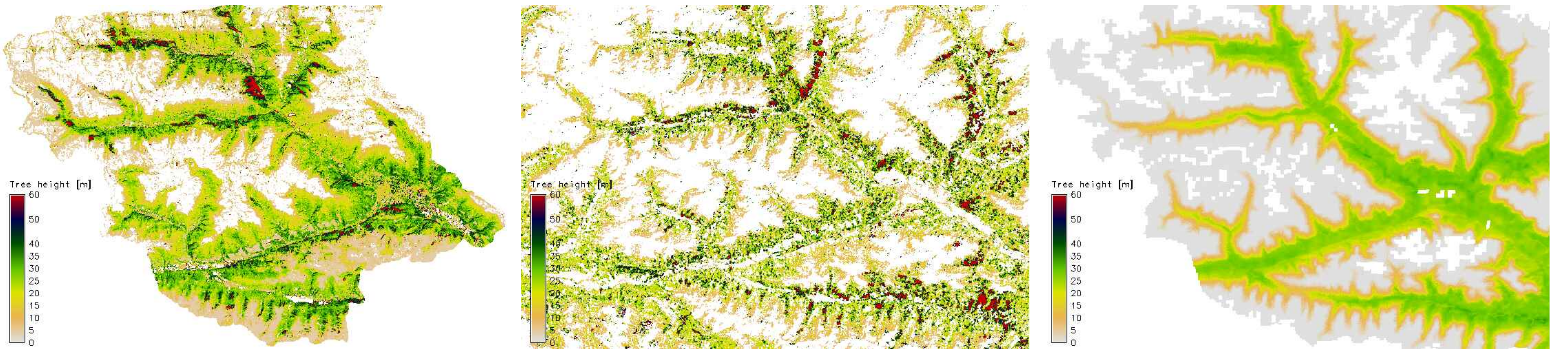
So lets compare the estimated site index from the heights of BFW for the years 2015 and 2021 with those from Glad from the years 2000 and 2020 and those estimated with the model 3WME (Kindermann, 2021). A map of Site Index for Osttirol is given in figure 13 where the estimated values for all methods are aggregated to a resolution of 90×90 m. The main picture looks similar. 3WME is much smoother than the others as it is using site characteristics which are only available on lower resolution and are model estimates which tend to be smooth. Also 3WME looks like to underestimate the side index for low productive forests near the tree boundary. Glad is able to give a similar picture than the others even thought that the given heights are only available in 1 m steps. Here the long time horizon of 20 years definitely helps in this case but still values on a better than 1 m scale would definitely help. The correlation between BFW and Glad is 0.21, BFW and 3WME 0.34 and 3WME and Glad 0.30. The site indices derived from height increments sometimes gives unrealistic high values. The average site index of BFW is 21.6 m of Glad 16.5 m and of 3WME 8,7 m. The standard deviation between BFW and Glad is 13.1 m, BFW and 3WME 12.1 m and 3WME and Glad 12.3 m. Scatter plots of the estimated site index are given in figure 14.

In figure 15 the site index differences between the methods are shown and plotted over altitude, aspect, stand density and slope. Between 3WME and Bfw there is a trend over *altitude* where both are approximately equal on low altitude where 3WME gives lower site indices than Bfw when the altitude is increasing. This trend is turning around 1900 m but still the Bfw site index is higher. A similar picture is given when comparing 3WME with Glad, but here Glad gives lower values on low elevation than 3WME. When comparing Bfw and Glad, Bfw shows higher values at low elevation and comes close to those of Glad by increasing altitude. When looking on *aspect* there seems to be a trend in the Bfw values compared to the others which have higher values in the east and lower values in the west. *Stand density* taken form Hansen u. a. (2013) show that both remote sensing methods have slightly increasing values by an increasing stand density. Increasing the slope from 0° to 20° causes an increasing site index of Bfw and Glad compared to 3WME.



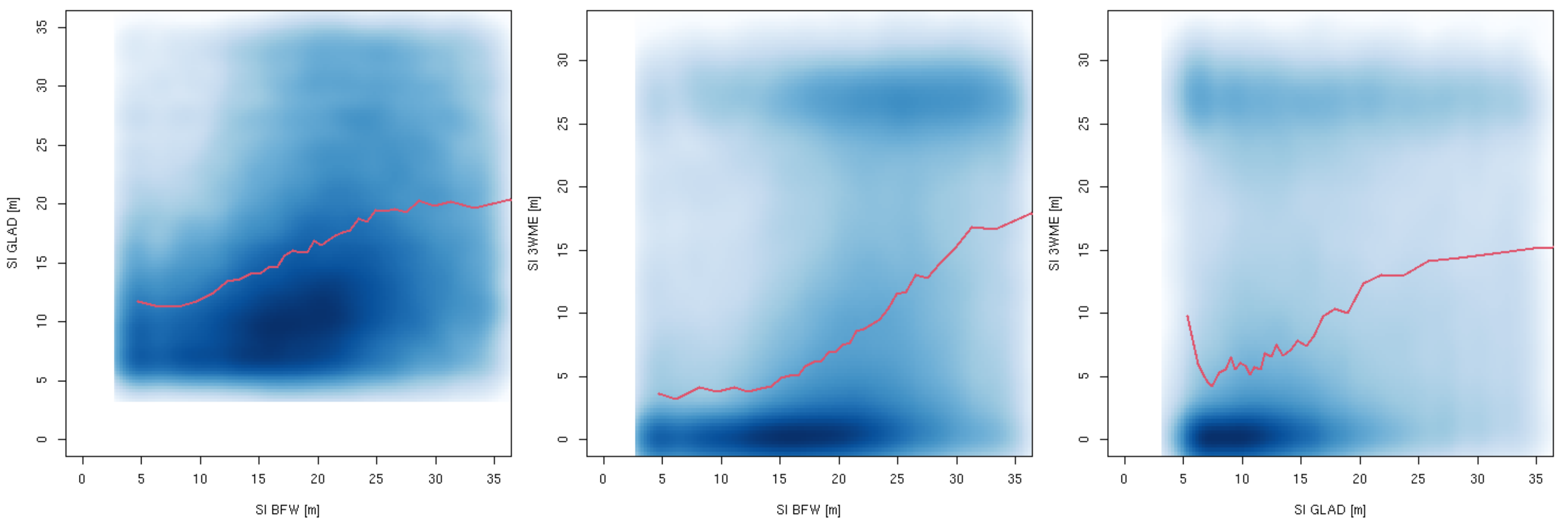
BFW 2021 – Glad 2020 | BFW 2021 – Eth 2020 | Eth 2020 – Glad 2020

Figure 12: Scatterplot of different height sources



BFW 2015 – 2021 | Glad 2000 – 2020 | 3WME

Figure 13: Site index (height at age 100) form different sources



BFW – Glad | BFW – 3WME | Glad – 3WME

Figure 14: Scatterplot of different Site Index estimates

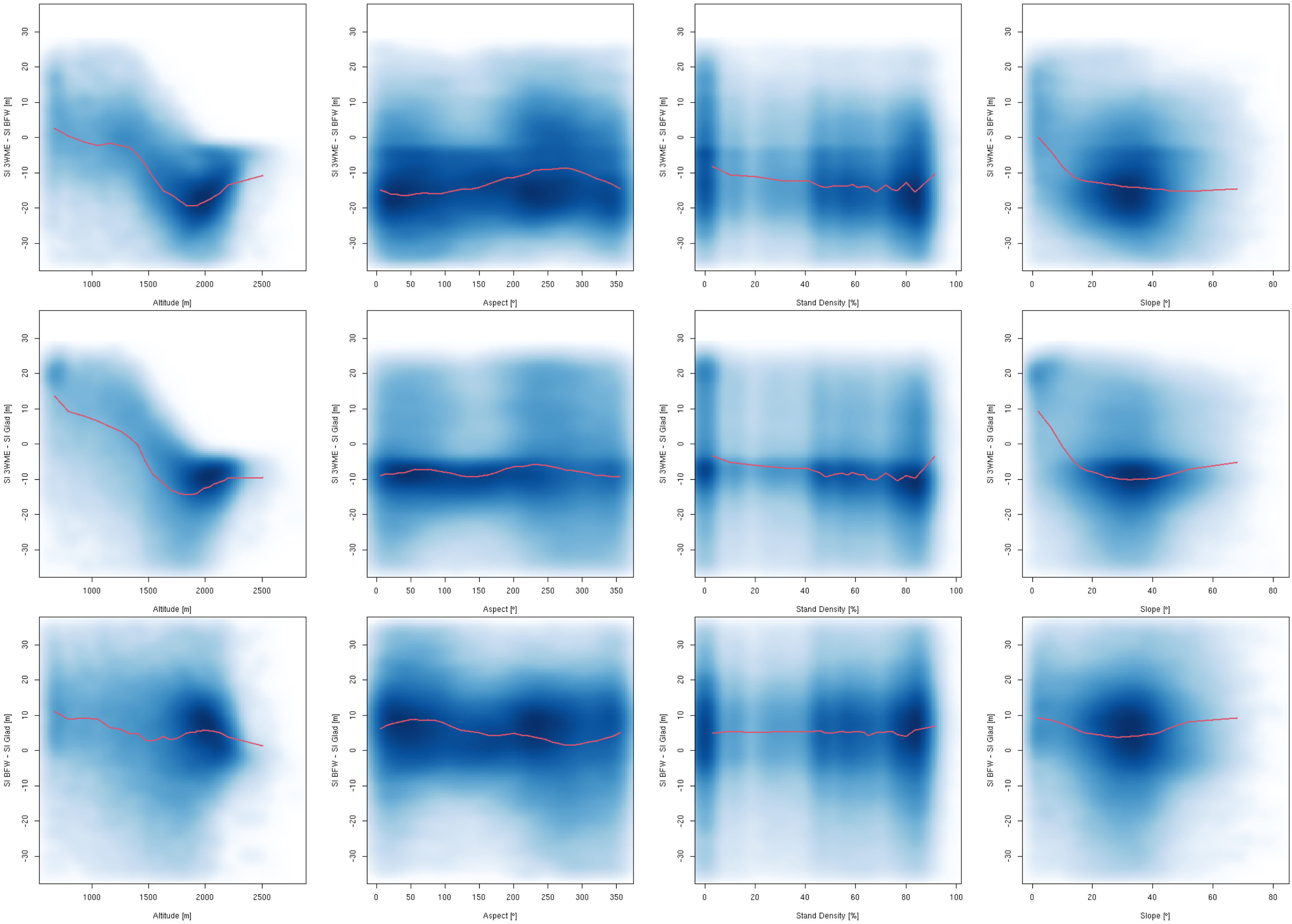


Figure 15: Site Index differences along Altitude, Aspect, Stand Density and Slope

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