Canopy gap fraction estimation from ICESat-2 ATL08 product

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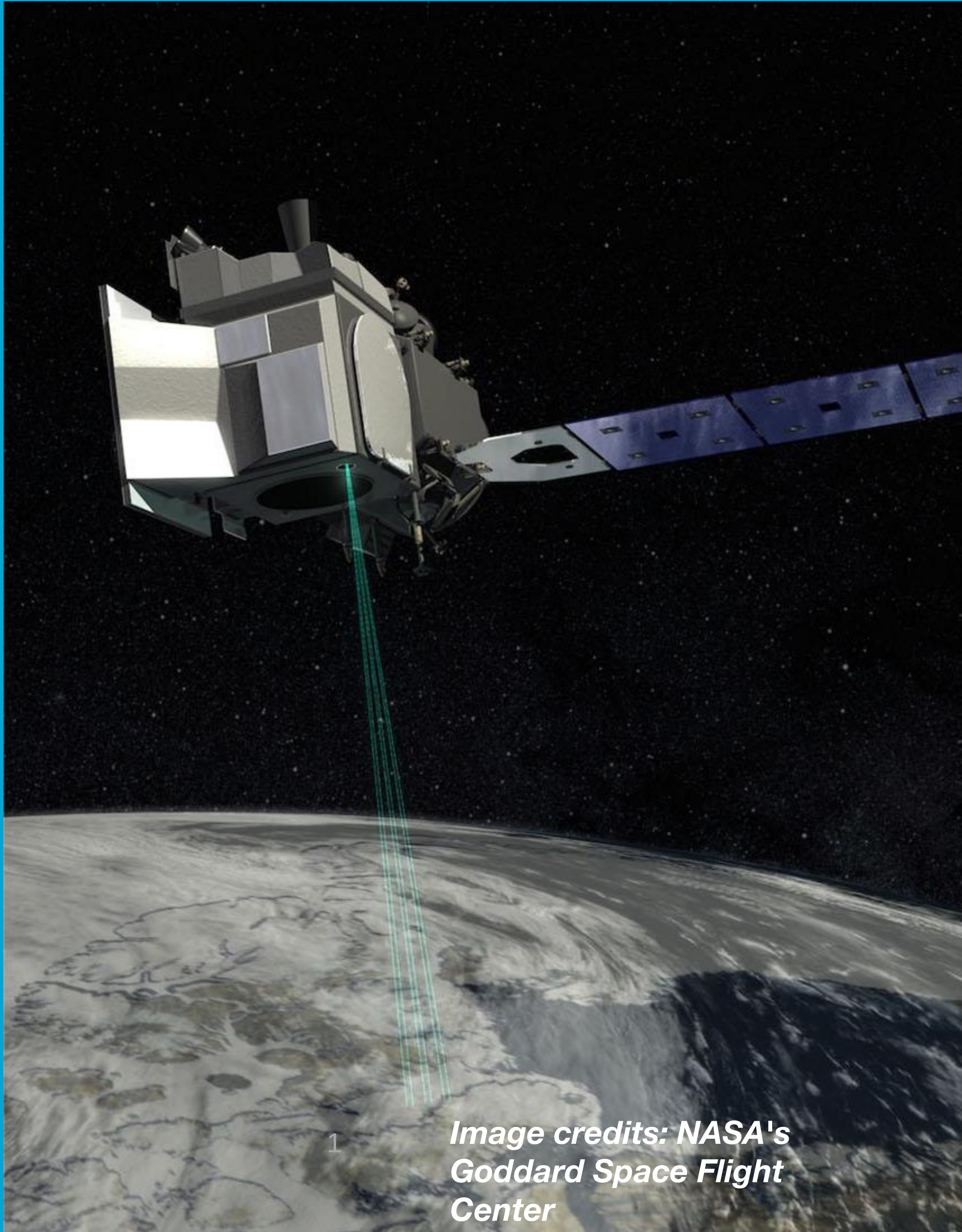
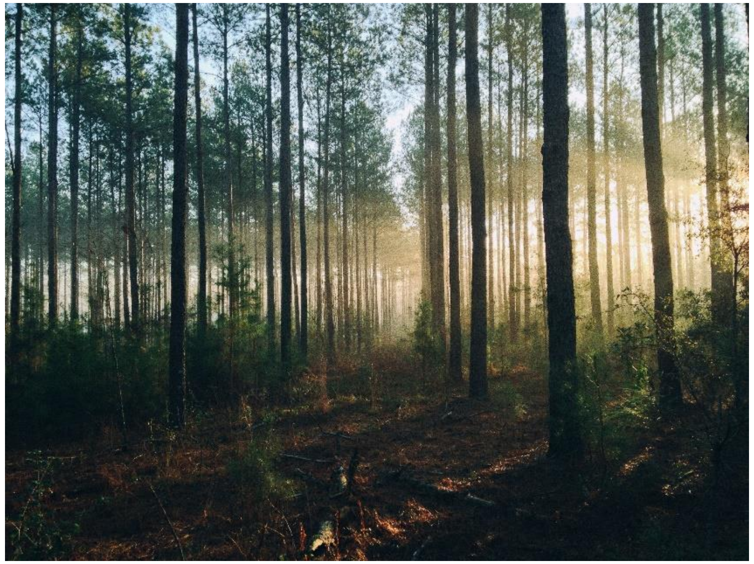
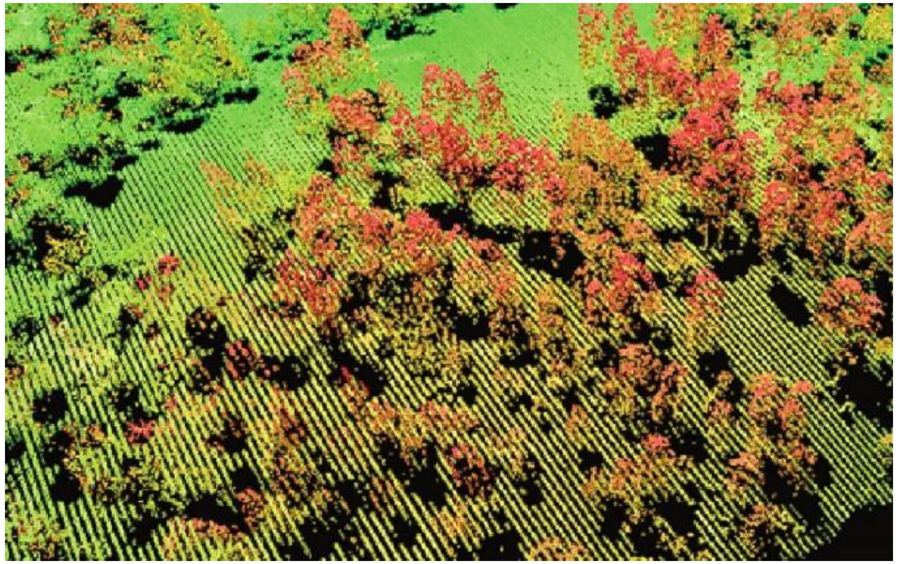


Image credits: NASA's Goddard Space Flight Center

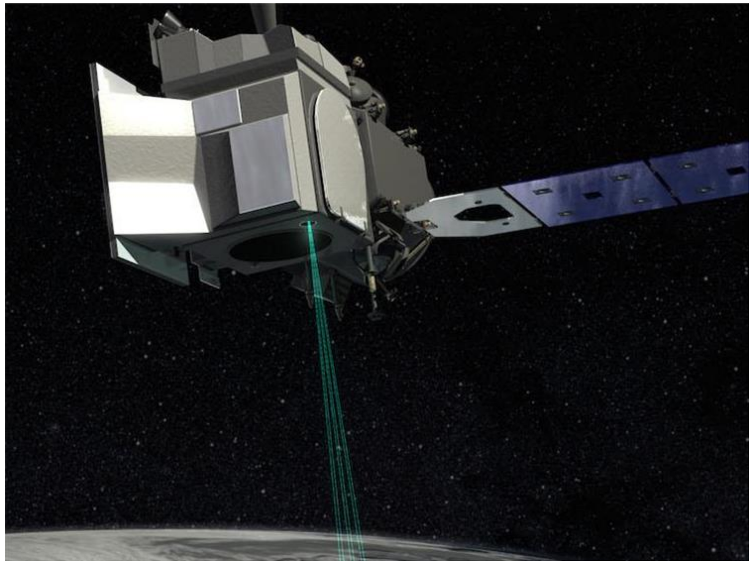
Motivation



- Forests **cover 31%** of the **global land** area;
- Most of terrestrial **biodiversity**;
- Supply **water**;
- Mitigate **climate change**;



- Estimating **forest structure** in 3D **using LiDAR** scanning **well researched;**
- Such data has **limited spatial** and temporal **coverage**;



- **ICESat-2** is designed to study the **cryosphere**;
- It also already has **ATL08** data product **for vegetation**;
- **Research is ongoing** to estimate canopy gap fraction from the ATL08 data;

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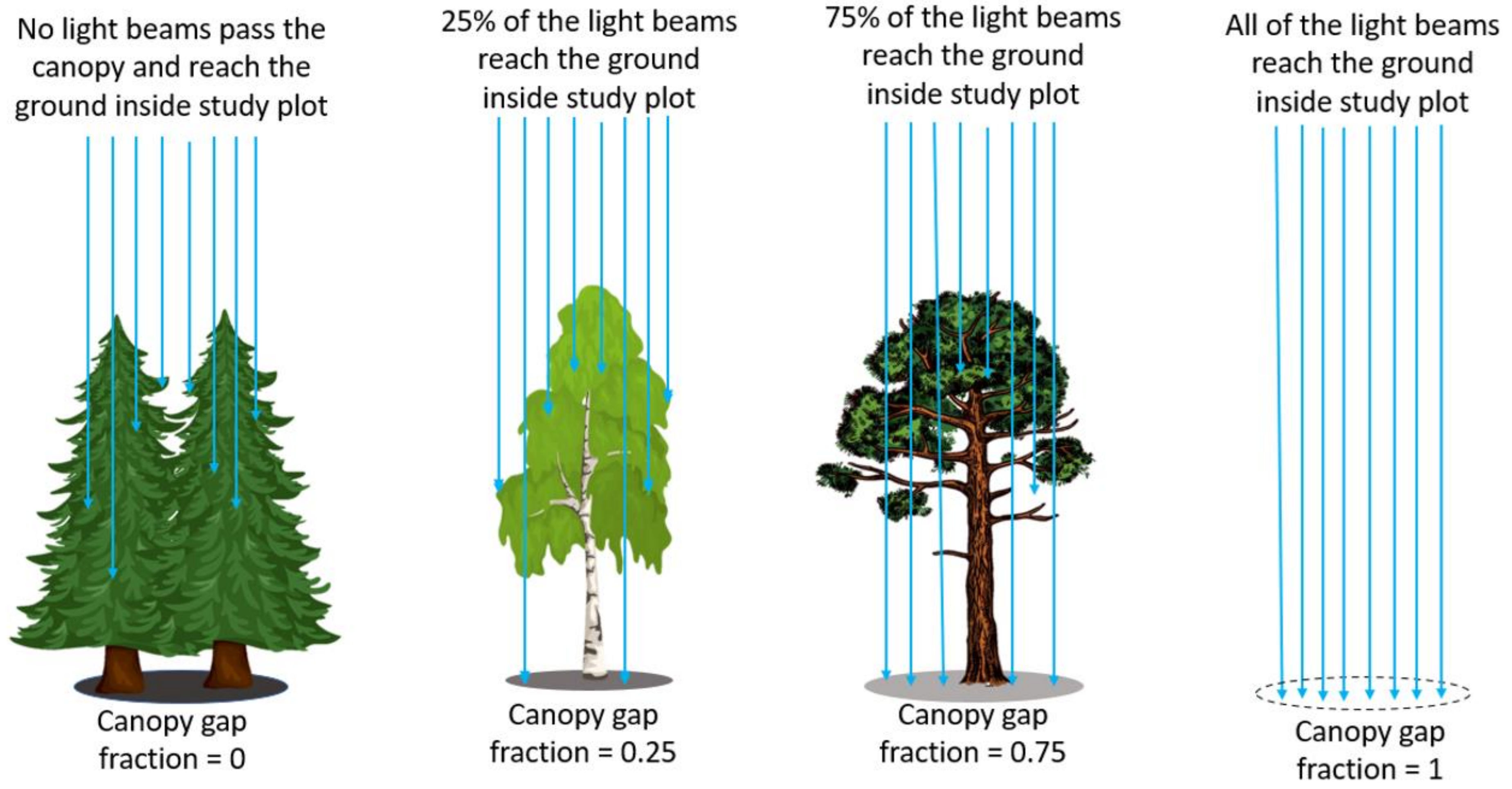
Background: Canopy gap fraction



$$Canopy\ gap\ fraction = 1 - \frac{\sum All_{canopy}}{\sum All}$$

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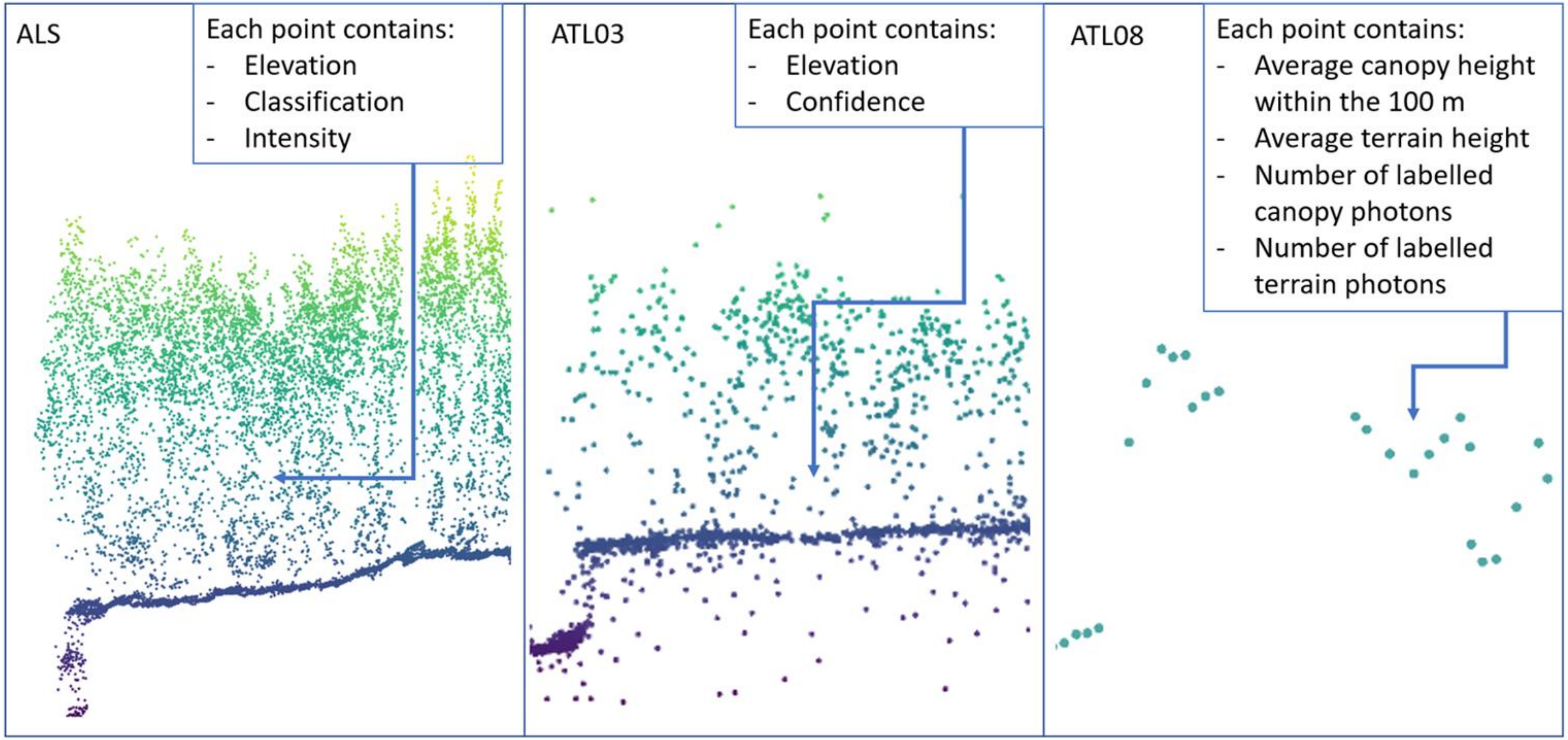
Background: Airborne Laser Scanning vs ATL08



Return recorded whenever the power of the waveform exceeds a fixed threshold.

The time when a single photon is detected recorded.

State of the art

- The **ATL08 version 5** data product is available;
- **Canopy height** data is **included;**
- There are **plans to include canopy gap fraction** data in future versions;
- There are **two approaches suggested** for deriving canopy gap fraction from ATL08 data;
- There has **not been a study publishing results** on computing canopy gap fraction from ICESat-2 data;

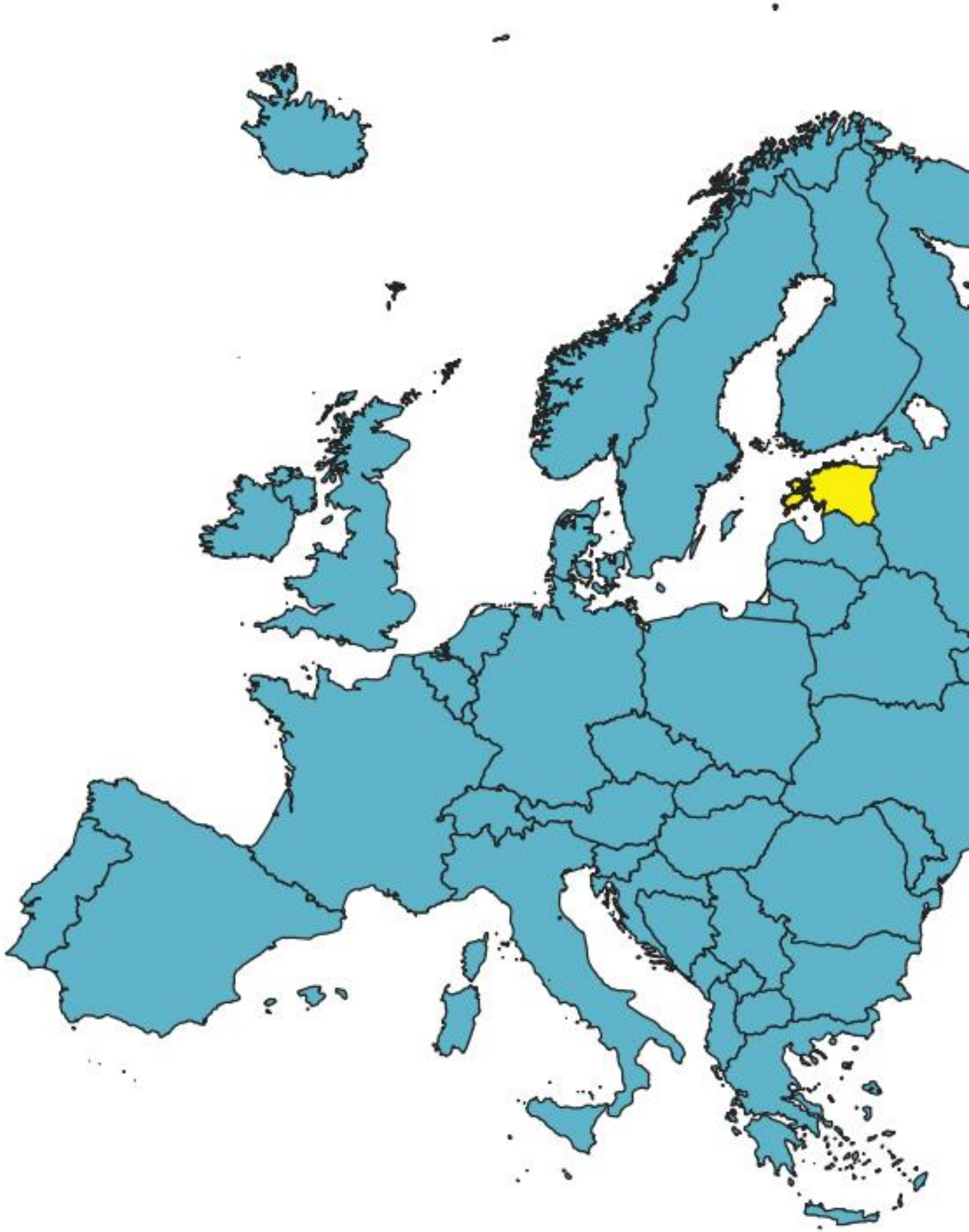
To what extent can canopy gap fraction be estimated from ICESat-2 ATL08 product?

Sub-questions

- What are the **optimal environmental conditions for ICESat-2** data acquisition that allow canopy structure estimation from ATL08?
- **Out of the two methods used** in this thesis for estimating canopy gap fraction from ICESat-2 data, **which performs better**?
- Does the canopy gap fraction derived from ATL08 reflect **differences in different forest types**?
- To what extent does the canopy gap fraction derived from ATL08 reflect the **changes in forest structure throughout the year?**
- To what extent i**s the ALS data provided by Estonian Land Board suitable** for validating canopy gap fraction estimation from ATL08?
- **How could the methods** for computing canopy gap fraction from ICESat-2 ATL08 data **be further improved?**

Study area and data used

- **ATL08 version 5** from National Snow and Ice Data Center
- **Airborne LiDAR** data **from spring and summer** scanning from Estonian Geoportal;
- Hansen **Global Forest Change** dataset (Hansen et al. 2013
- Raster of **forest types** by dominant tree species in Estonia (Lang et al. 2018).



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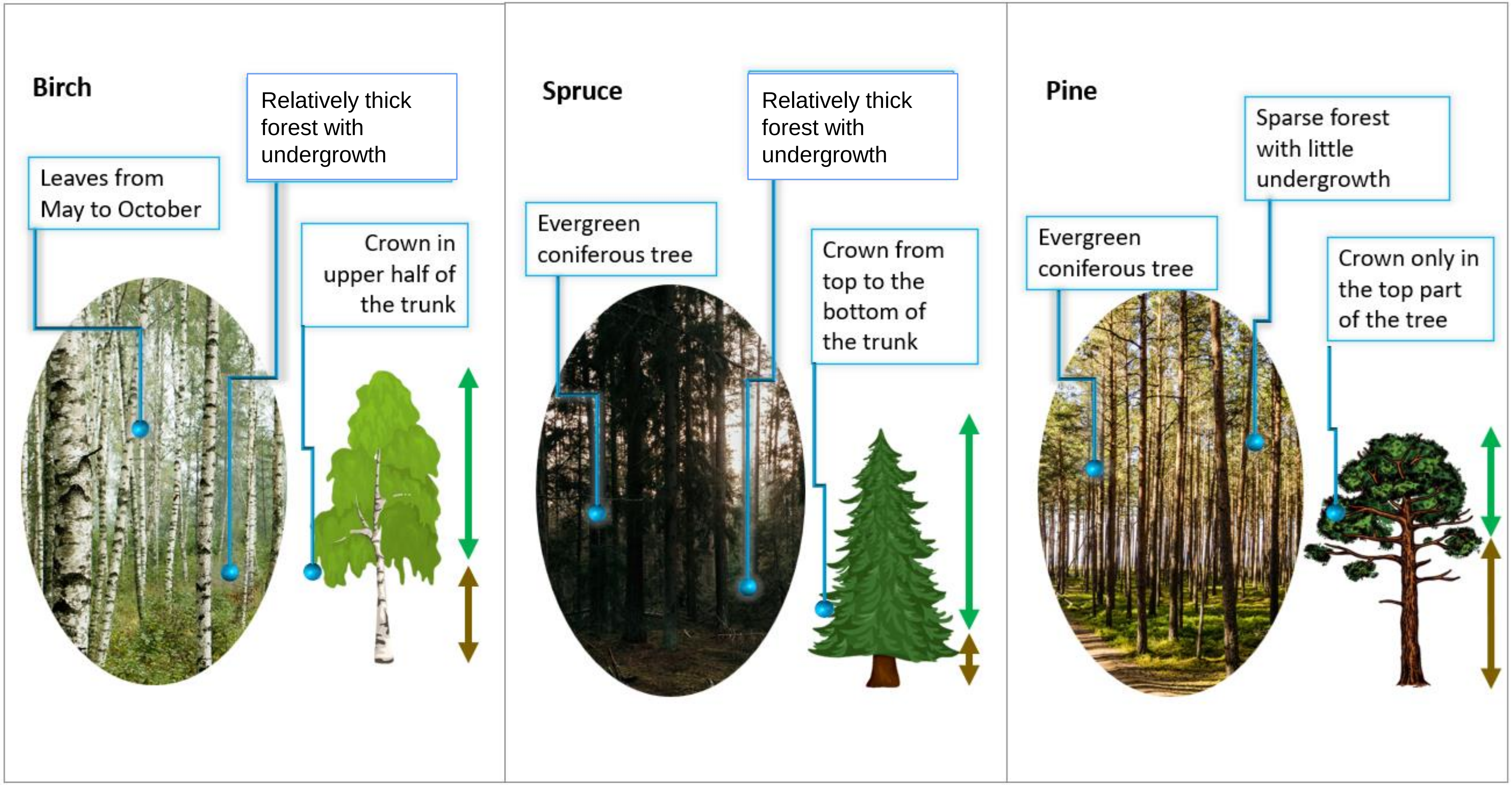
Study area



Birch
Relatively thick forest with undergrowth
Leaves from May to October
Crown in upper half of the trunk
Spruce
Relatively thick forest with undergrowth
Evergreen coniferous tree
Crown from top to the bottom of the trunk
Pine
Sparse forest with little undergrowth
Evergreen coniferous tree
Crown only in the top part of the tree

Workflow

1. ATL08 data preparation

- Filtering
- Polygon geometry
- Tree Cover information

2. ALS data preparation

- Clipping
- Canopy gap fraction
- Solberg's Cover Index

3. Validation

- ALS gap fraction vs ground data
- ALS vs ATL08 canopy height
- Radiometric histogram

4. Canopy gap fraction from ATL08

- Canopy to total photon ratio
- Using radiometric profile

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Methods for ALS

$$Canopy\ gap\ fraction = 1 - \frac{\sum All_{canopy}}{\sum All}$$

$$\mathcal{SCI} = 1 - \frac{\sum Single_{ground} + 0.5(\sum First_{ground} + \sum Last_{ground})}{\sum Single_{all} + 0.5(\sum First_{all} + \sum Last_{all})}$$

Methods for ATL08

$$Canopy\ gap\ fraction\ _{ATL08} = 1 - \frac{\sum R_{topcanopy} + \sum R_{canopy}}{\sum R_{topcanopy} + \sum R_{canopy} + \sum R_{terrain}}$$

$$Canopy\ gap\ fraction\ _{ATL08} = 1 - \frac{\sum_{z_i}^{z_{max}} R_v}{1 + \frac{\rho_v}{\rho_g} \frac{R_g}{R_v}}$$

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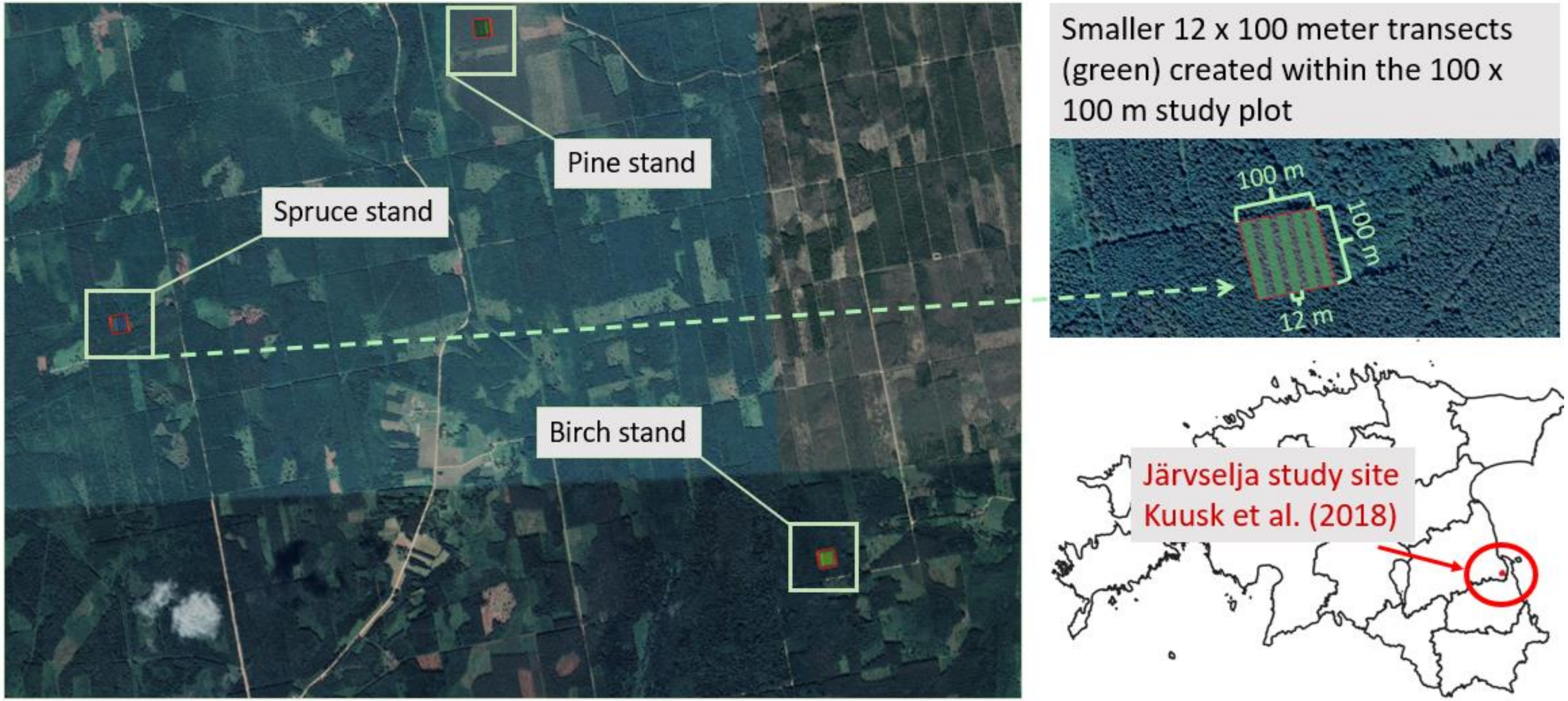
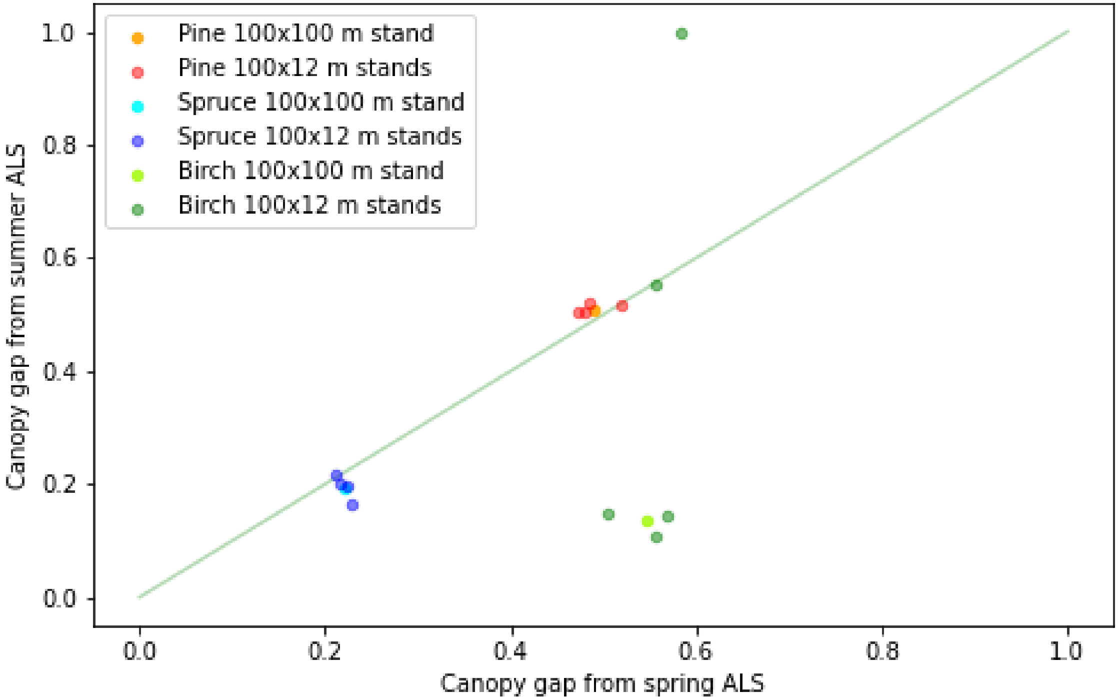
Validation 1: ALS CGF compared to reference data (1/3)



Validation 1: data from spring and summer (2/3)

- Canopy gap fraction was computed from the **summer and spring ALS data**;
- **Agreement** between the two datasets for **pine and spruce**;
- **Different results for birch** reflecting the change in **seasons**;
- **Noise in birch** stand data indicating possible errors in the ALS data.



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Validation 1: ALS gap fraction compared to reference data (3/3)

- **SCI has better agreement** with reference data than ALS canopy gap fraction;
- **Best agreement** between computed and reference data **in pine stand**;
- **For spruce and birch** stands the computed values **underestimate**;
- Due to **lower resolution of ALS** used in this thesis, in **dense forest** CGF may be **underestimated**;

	Reference ALS CGF	Computed CGF	Computed SCI
Pine stand	0.55	0.53	0.54
Birch stand	0.3	0.18	0.25
Spruce stand	0.35	0.19	0.24

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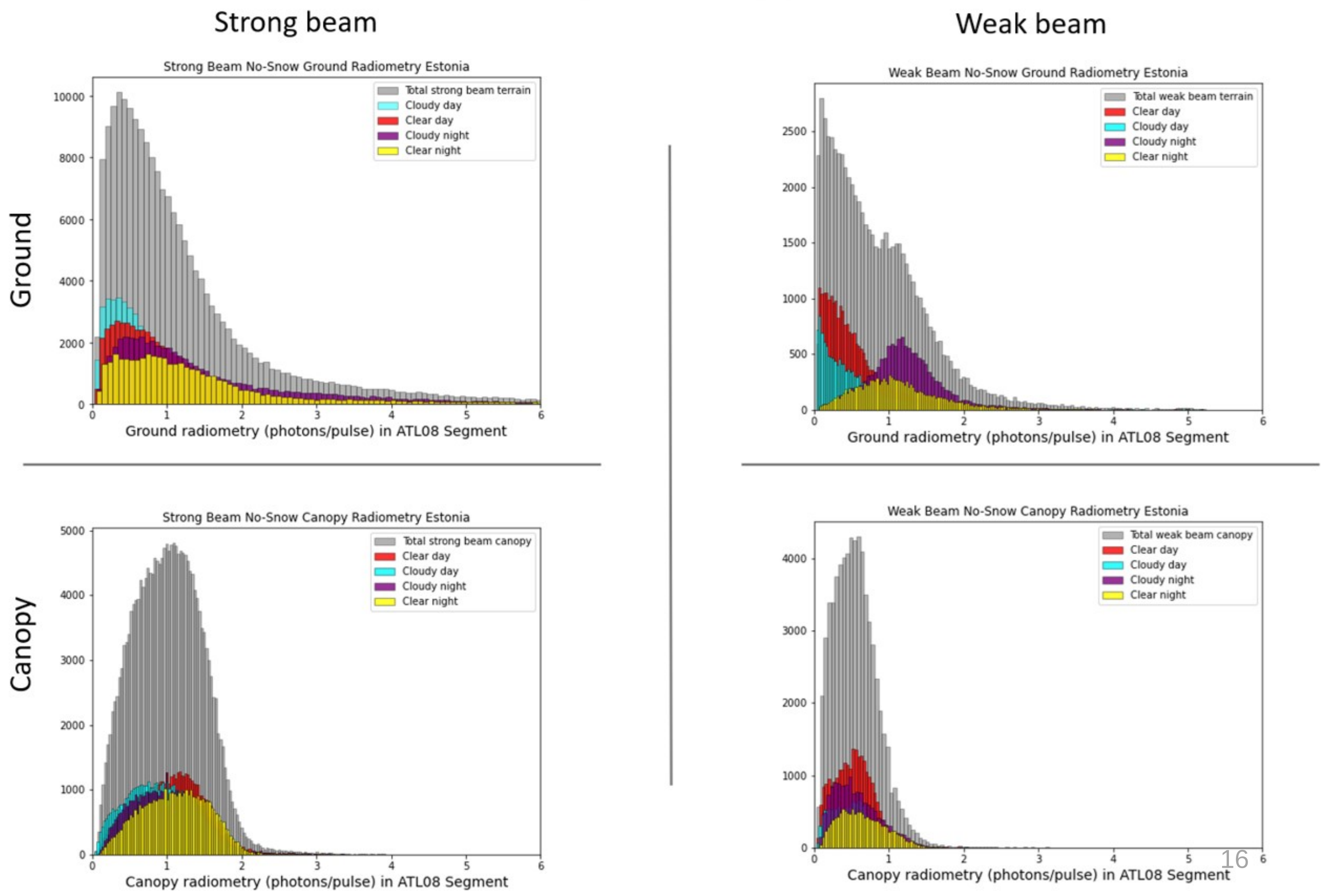
Validation 2: Histograms

- To understand **how** ground and canopy **radiometry performs**;
- **Clear difference** between daytime and nighttime radiometry can be seen **in the weak beam;**
- Nighttime conditions are more optimal than daytime;
- Weak beam ground mode always higher than canopy;



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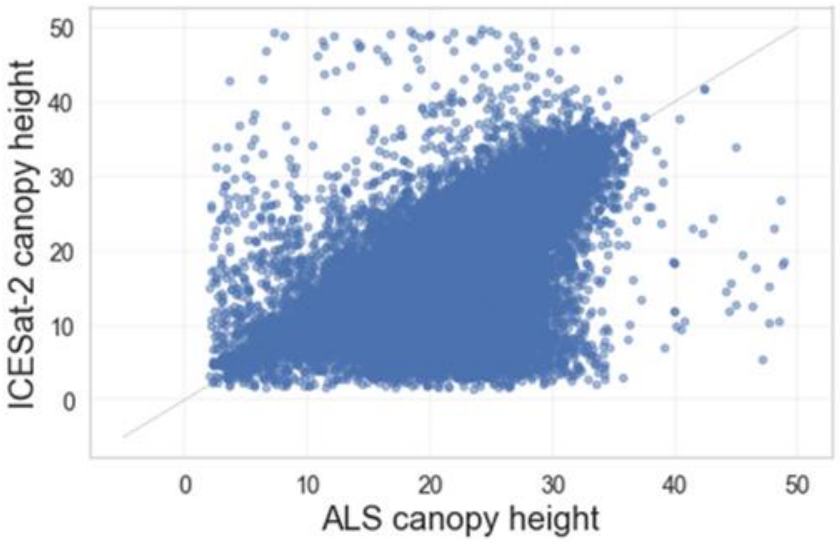
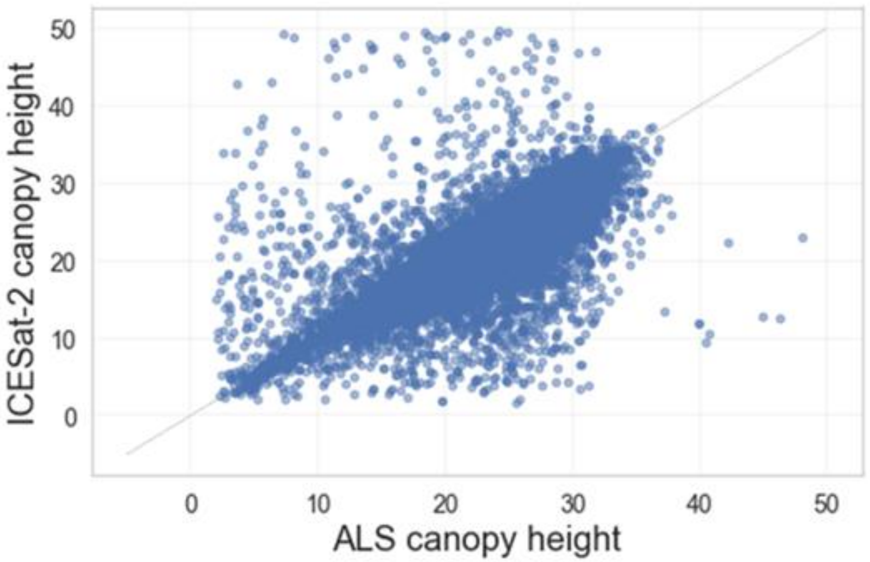
Validation 3: Canopy height estimation from ALS and ATL08

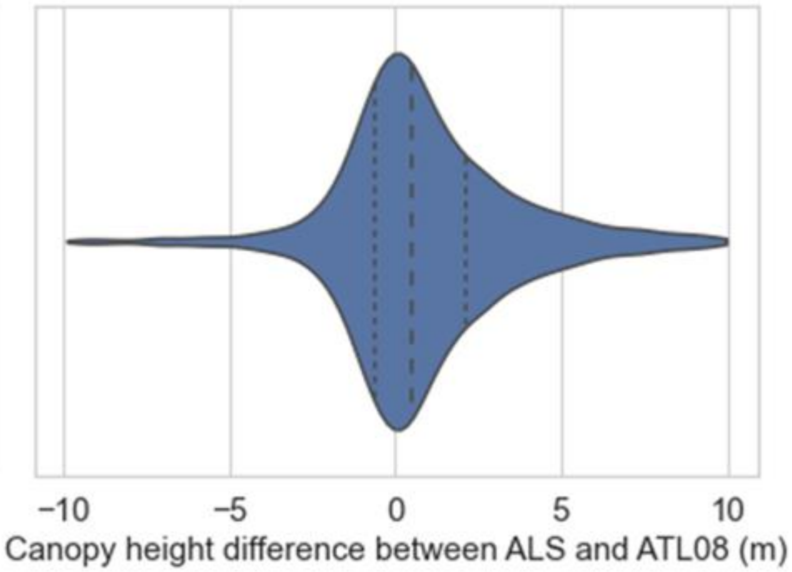
- Day and night included

Only night included

Violin graph







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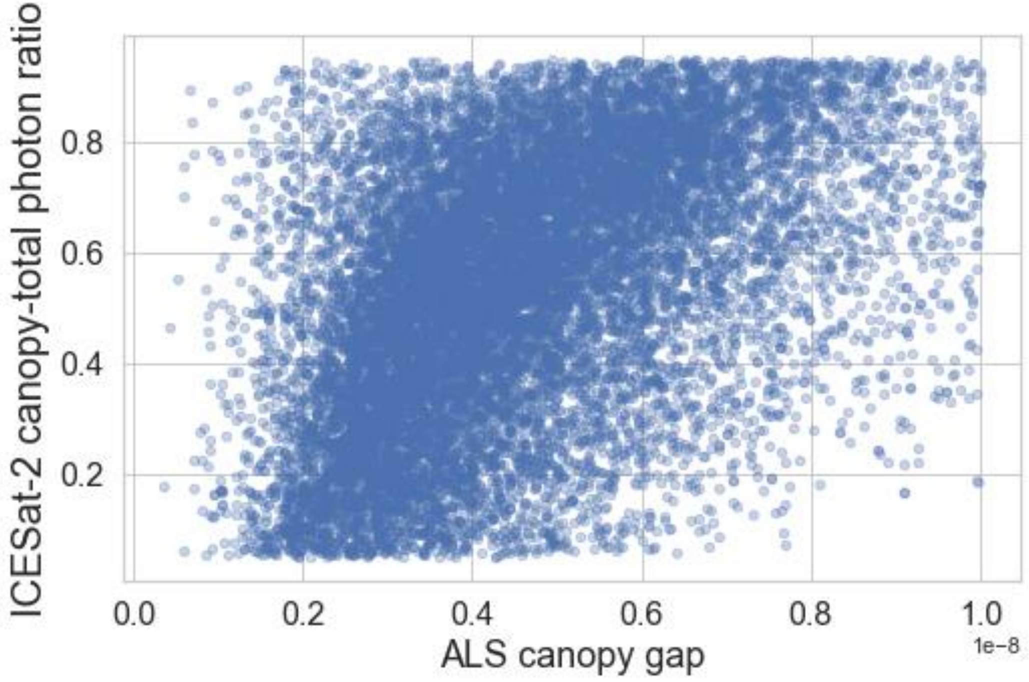
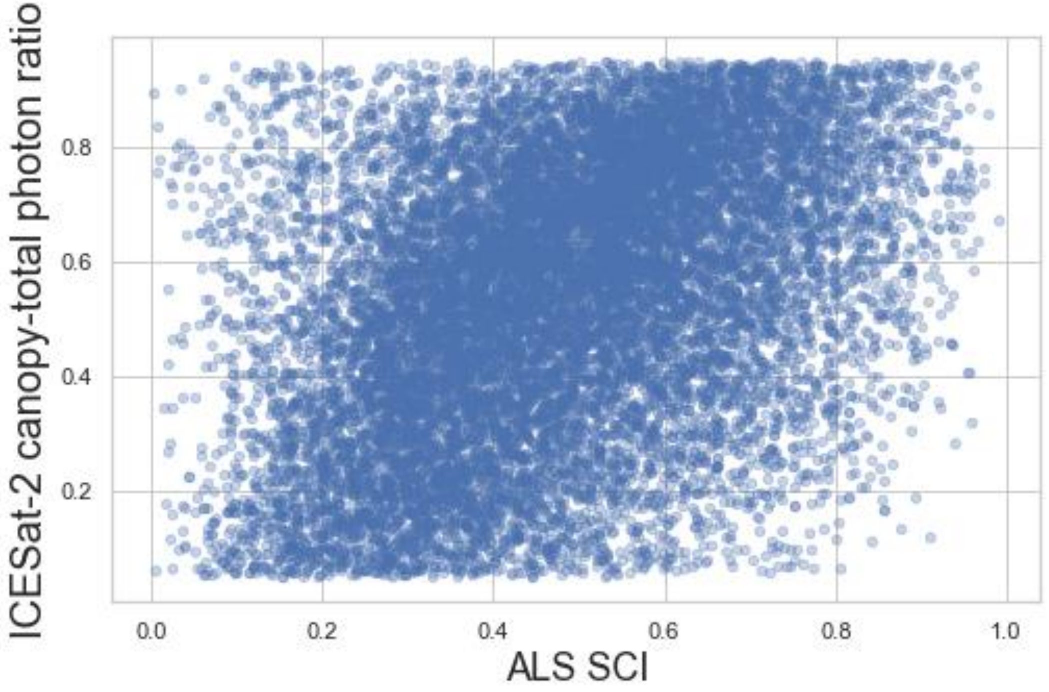
Results

Method I: canopy to total photon ratio

- **ATL08 tends to overestimate** the canopy gap fraction
- **Better fit with the SCI** than the canopy gap fraction value





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Method II: using radiometric profile (1/3)

$$p_{gap}(z) = 1 - \frac{\sum_{z_i}^{z_{max}} R_v}{1 + \frac{\rho_v}{\rho_g}\frac{R_g}{R_v}}$$

Reflectivity

▪

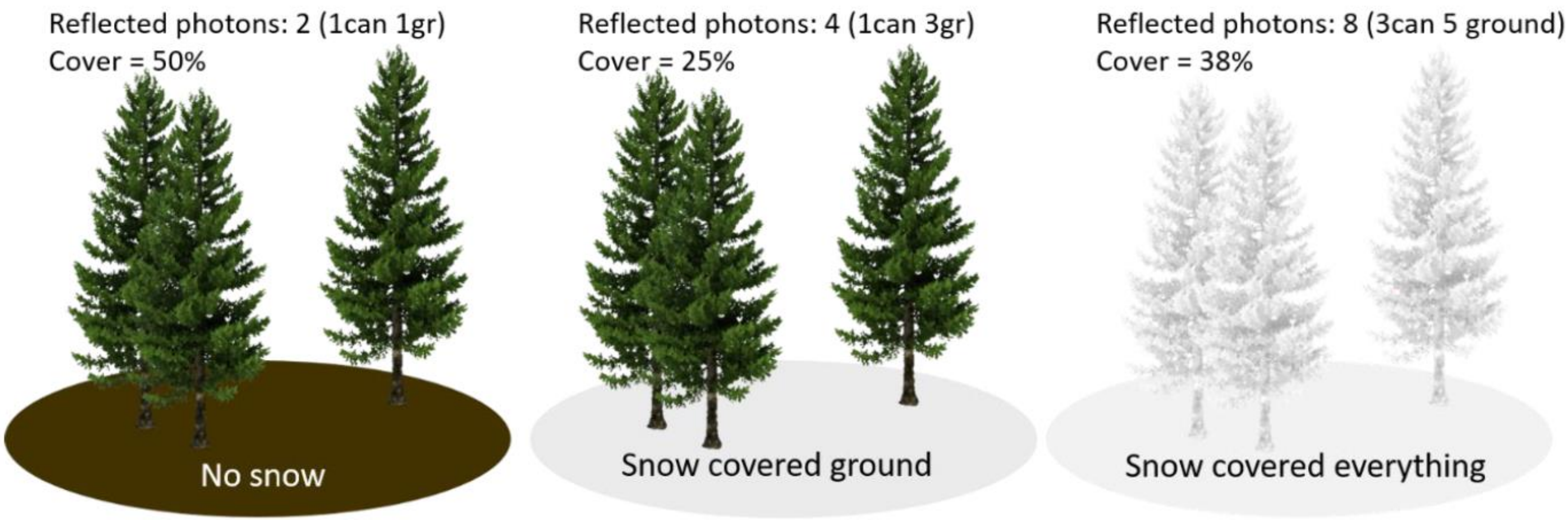
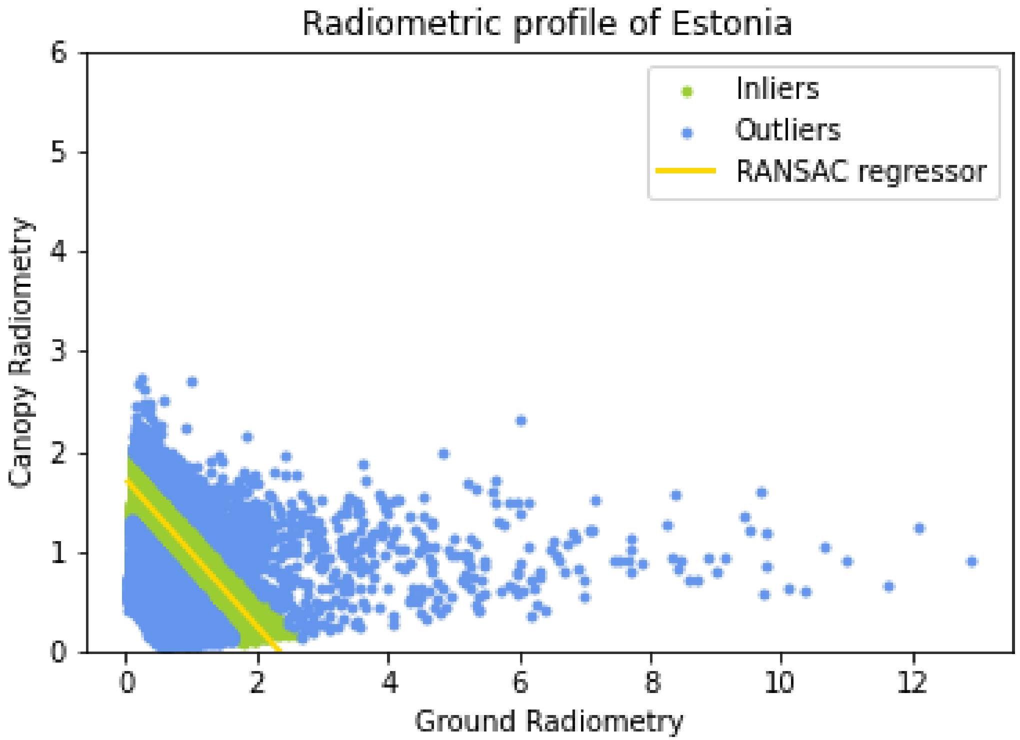


Figure taken from Neuenschwander et al. 2022

Method II: using radiometric profile (2/3)

- Y-intercept shows transects where all labelled photons from the canopy;
- Y-intercept around 1.8;
- X-intercept around 2.3;
- Ground reflectivity is higher than the reflectivity of vegetation.



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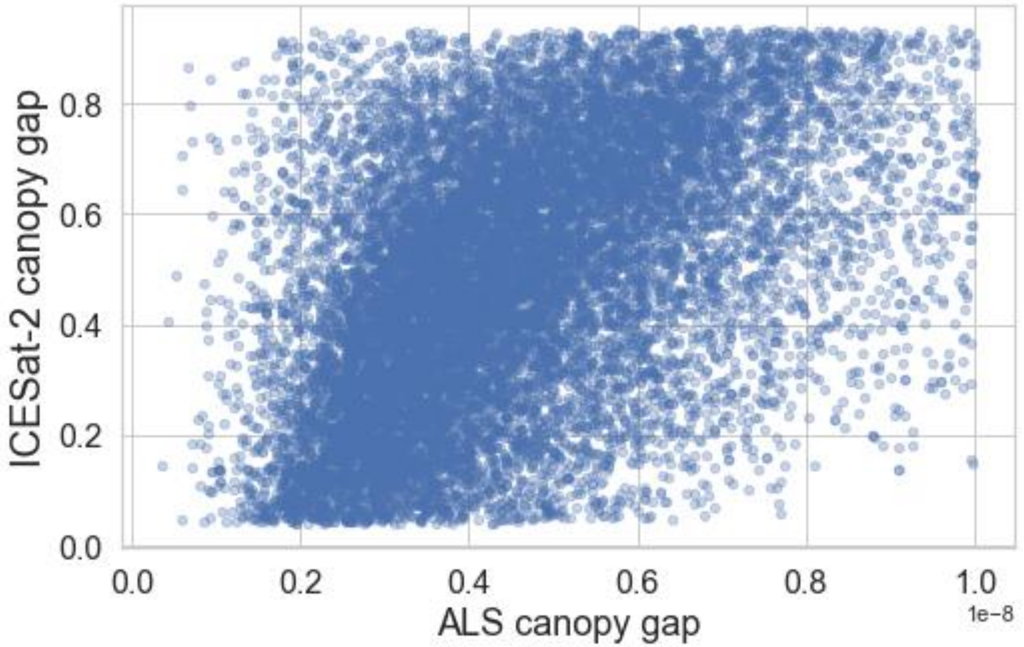
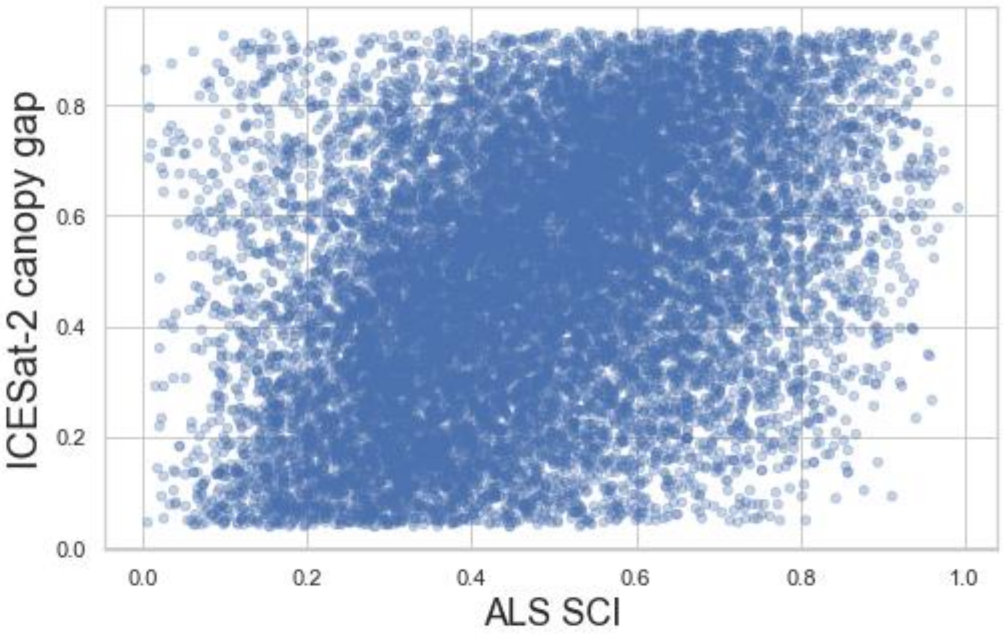
Method II: using radiometric profile (3/3)

- Overestimation in the results computed from ATL08
- Correction for reflectivity does not have too much effect on the results





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Which of the two methods is better?

- Both methods show very similar RMSE and the Mean Absolute Deviation (MAD);
- Noise in both;
- Second method is computationally more expensive;
- The first method of using canopy to total ratio should be preferred out of those two;

	CGF using photon ratio (Eq 3.3)		CGF with reflectivity correction (Eq 3.4)	
	ALS CGF	ALS SCI	ALS CGF	ALS SCI
RMSE	0.58	0.24	0.54	0.23
MAD	0.17	0.17	0.19	0.19

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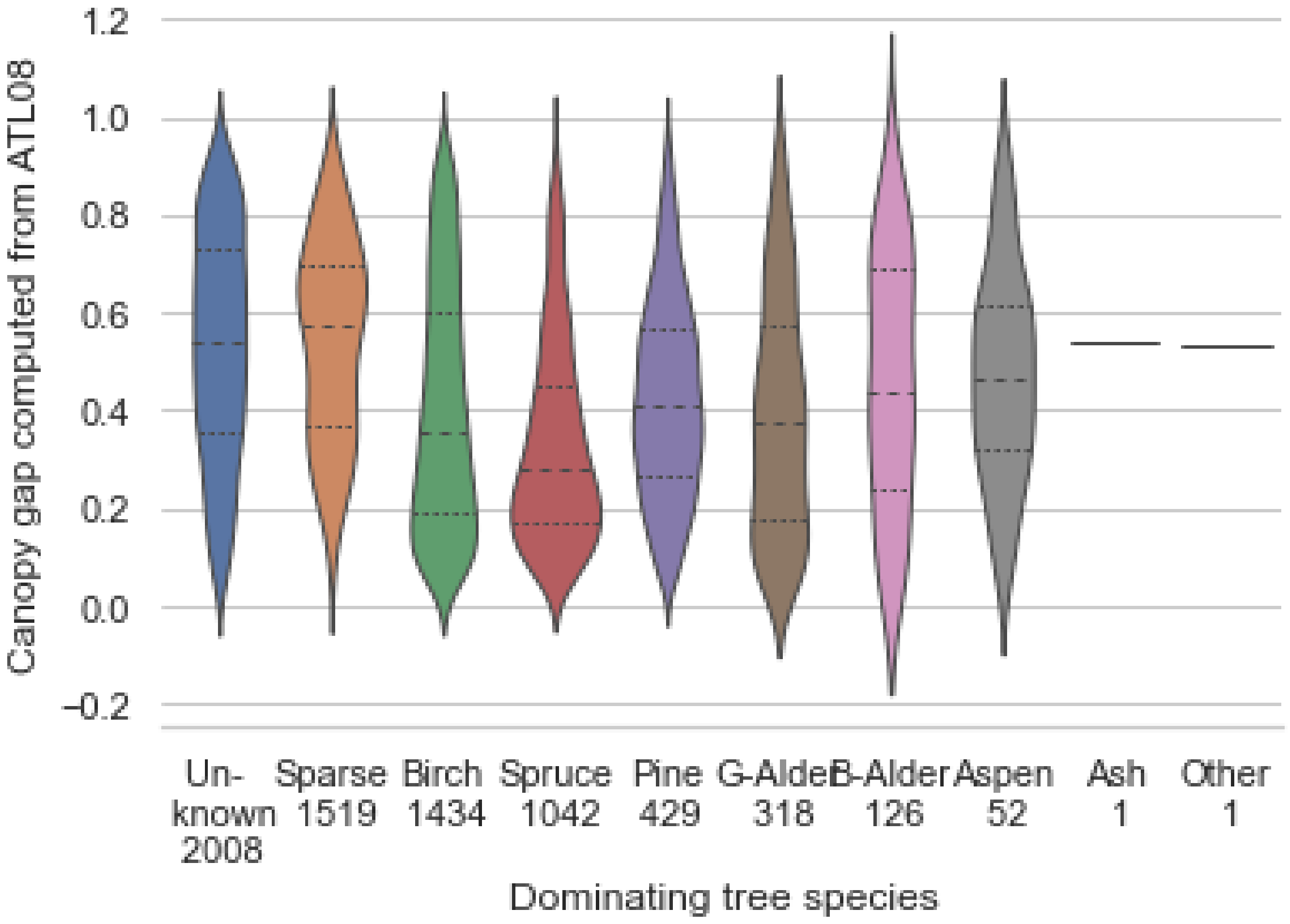
Canopy gap in different **forest types**

- Data only from **summer months**;
- Only segments where **species variety low**;
- The median **CGF lower for spruce and birch** than for pine forest;
- However, dominant tree species is not a strong indicator to be used as ground truth for estimating forest density.



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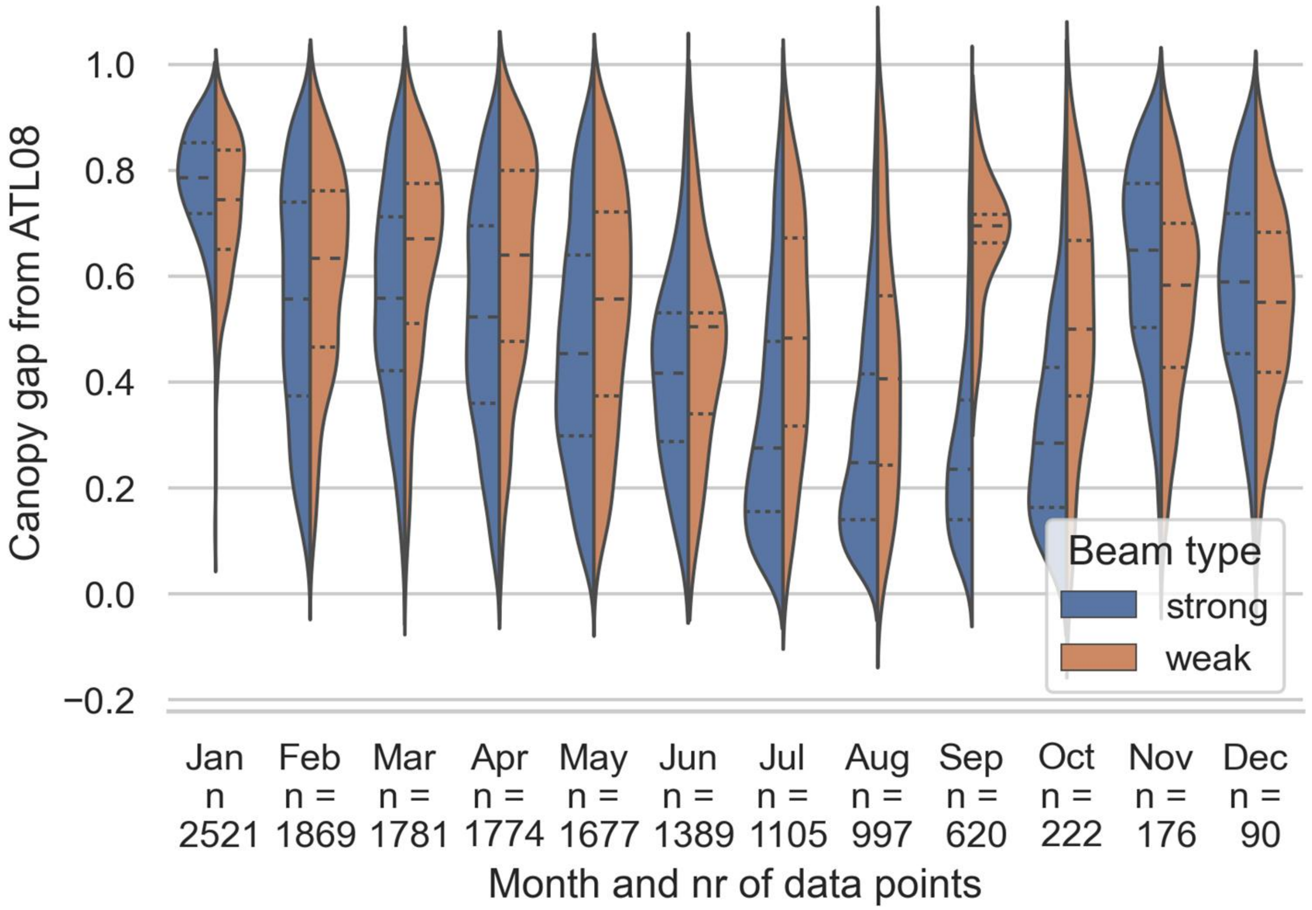
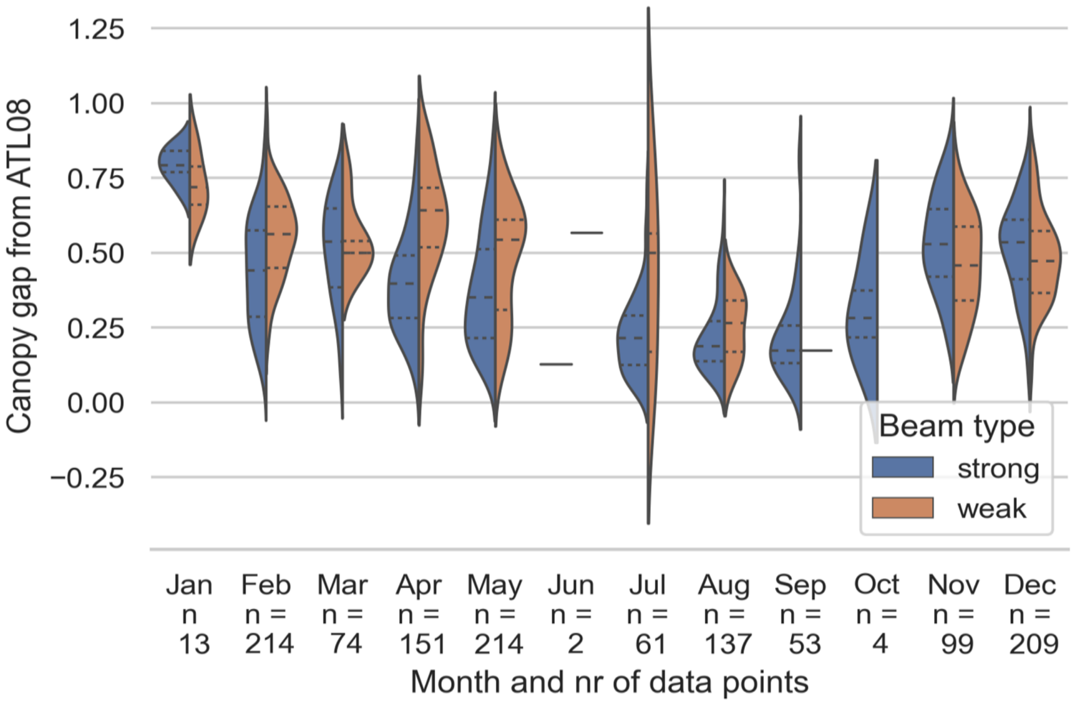
ATL08 canopy gap fraction **through the year** (1/2)

- CGF **higher from November to April;**
- **Low from May to September;**
- Trend is more clear in the strong beam;
- Does it reflect changes in vegetation or changes in reflectivity?

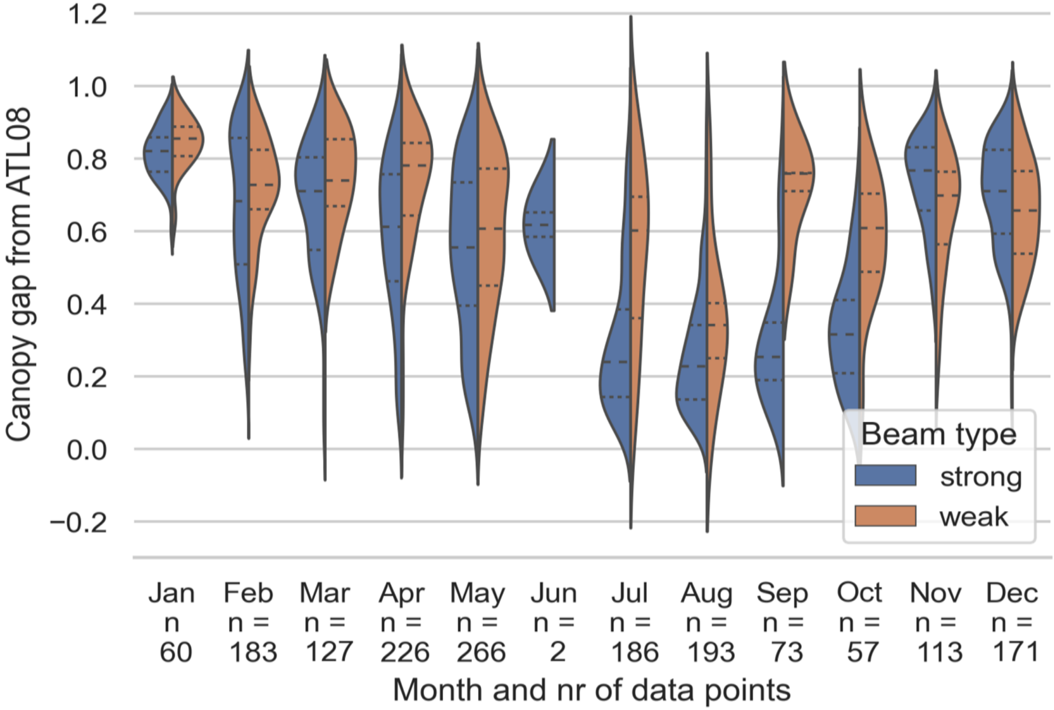


ATL08 canopy gap fraction **through the year** (2/2)

Spruce (evergreen)



Birch (deciduous)



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Key takeaways

- The ALS data used did not meet the resolution suggested by the ATL08 technical document and there were some possible errors in the data;
- Nighttime acquisition is more optimal than daytime for using ATL08 weak beam data;
- The two methods tested in this thesis gave similar results;
- The method using canopy to total photon ratio is considered better;
- The ATL08 data can show different canopy gap fraction in different forest types;
- The ATL08 data can also indicate annual changes in forest structure;

Future work

- Higher quality ALS data should be used to have higher confidence in the reference data;
- Once ATL08 version 6 is available, using version 5 is not recommended due to the errors in the daytime data;
- Correcting for the ground and vegetation reflectivity needs more research;
- The annual trends in vegetation reflected in ATL08 data could be promising for large-scale forest studies.
- Although ALS and TLS might give higher accuracy canopy gap fraction estimation, their spatial and temporal coverage cannot match the one of ICESat-2;

Thank you for your attention

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