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Retrieving forest understory gap fraction using an energy dimidiate model with airborne waveform LiDAR

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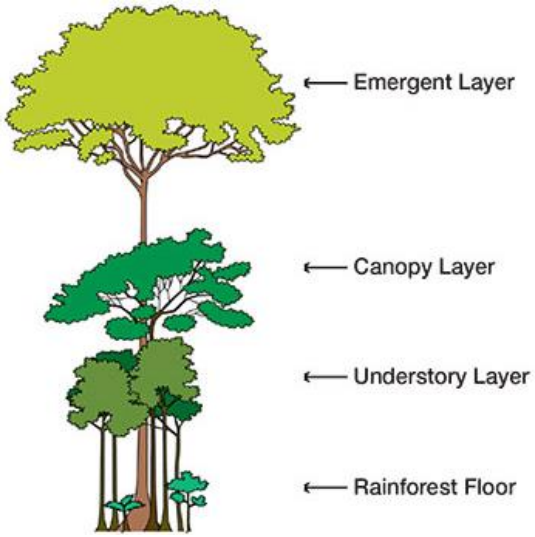
Please give some concerns on understory.

(Credit: Yang et al., 2023; Forsstrom et al., 2023; Crespo-Peremarch et al., 2018)

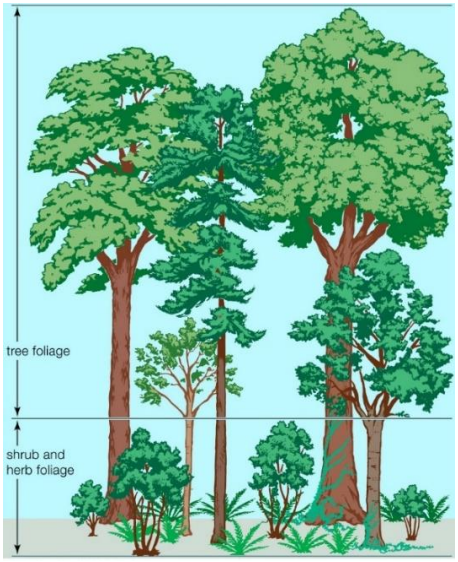
Function

✓fundamental data for ecological process, soil and water conservation, animal habitats,...

Tropical forest



Temperate broadleaf forest



Boreal forest

(Credit: Google)

How we characterize understory structure ?

Definition of gap fraction (GF)

- ✓ The probability of a light beam passing through the canopy without interacting with vegetation elements.
- ✓ Indicator of understory vegetation structure, related to biophysical variables.

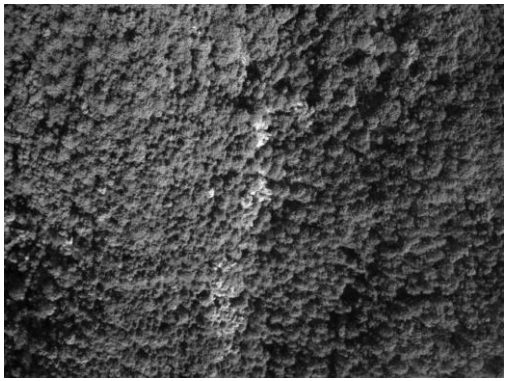
How to measure GF using RS techniques ?

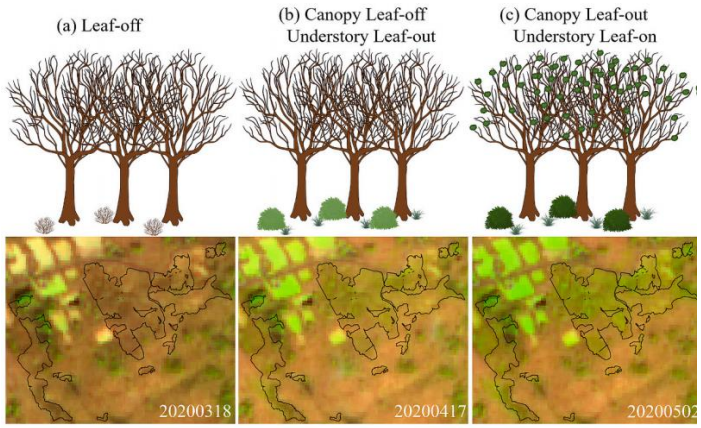
1 Passive RS to deal with understory

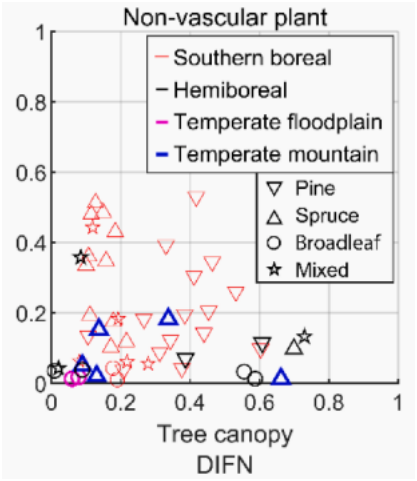
Ways

- ✓ RTM with multiangular RS
- ✓ unique phenological window with time-series RS
- ✓ nonlinear ecological relationship of two layers

Occlusion and shadow effect by upper canopy







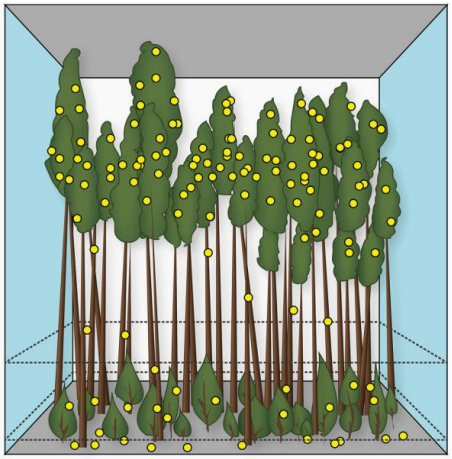
(Credit: Yang et al., 2023)

(Credit: Forsstrom et al., 2023)

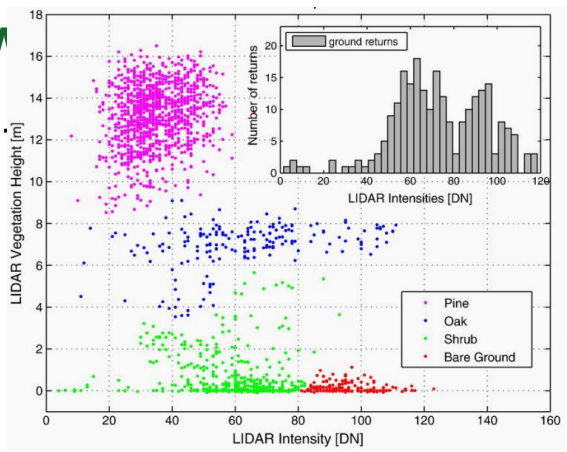
LiDAR: ability of penetration

- ✓ discrete-return LiDAR: return-number -based indices but limited by sparse point cloud (Sumnall et al., 2021; Campbell et al., 2018)
- ✓ full waveform LiDAR: simplified radiative transfer model of laser pulse with well-characterized understory info (Song et al., 2021)

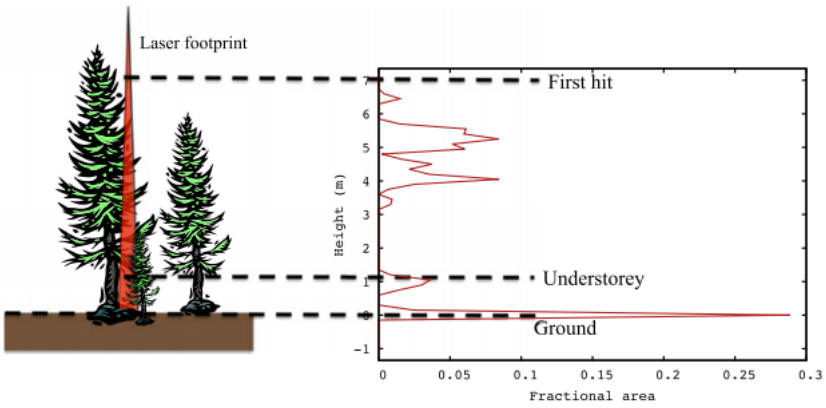
unsatisfied accuracy, low robustness



(Credit: Campbell et al., 2018)



(Credit: Morsdoef et al., 2010)



(Credit: Hancock et al., 2017)

A new method - energy dimidiate model (EDM)

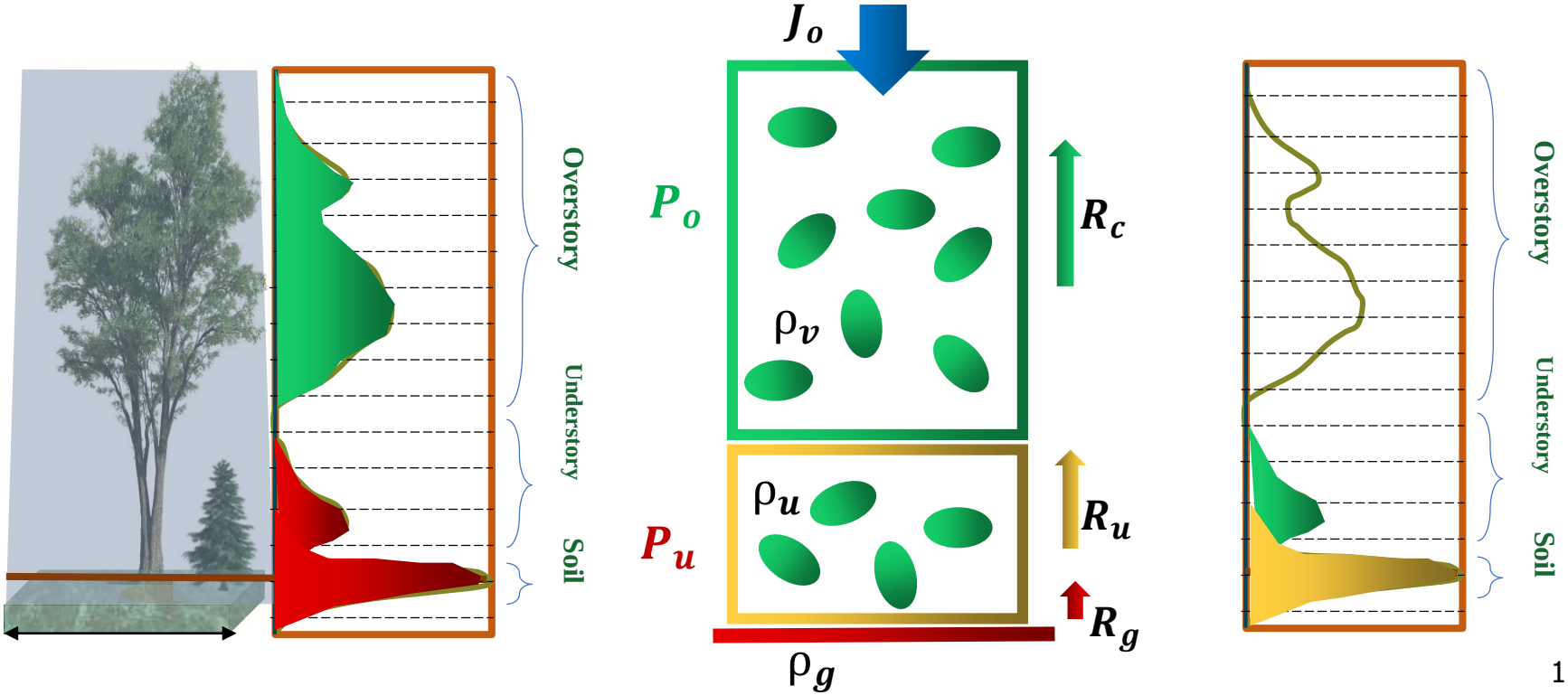
2 Basic idea of energy dimidiate model

- Total return energy is from two parts，i.e., upper and lower

$$R = R_c + R_m$$

- Lower-layer return energy is from two parts，i.e., vegetation and soil

$$R_m = R_u + R_g$$

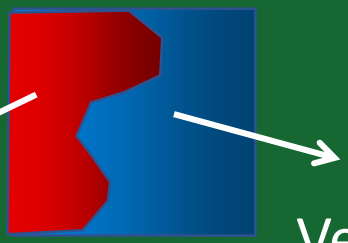


2 Basic idea of energy dimidiate model (continue)

- With RTM (only first-order scattering considered), we can form

$$R_m = R_u + R_g = J_0 \rho_u P_o (1 - P_u) + J_0 \rho_g P_o P_u$$

$$S = \rho_v (1-) + \rho_g f$$



- Only the understory backscattering coefficient is needed

$$R_m = R_u + R_g = J_0 \rho_u P_o (1 - P_u) + R_g$$

✓ we may extract the soil return energy directly form the waveform

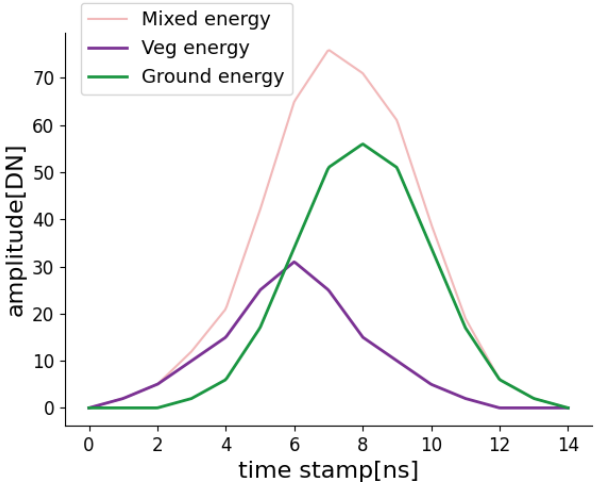
2 EDM model: solve the unknown parameters (R_g)

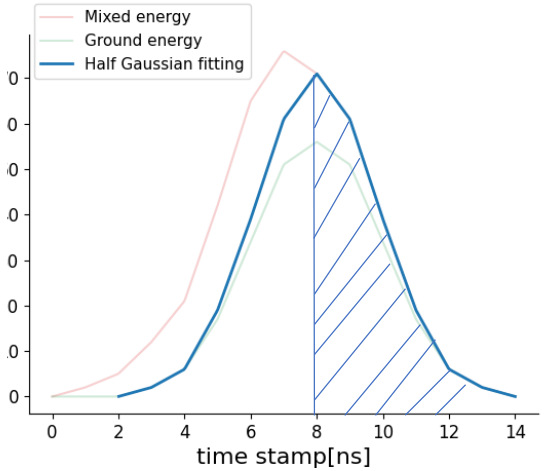
The soil echo can be seen as a Gaussian distribution model

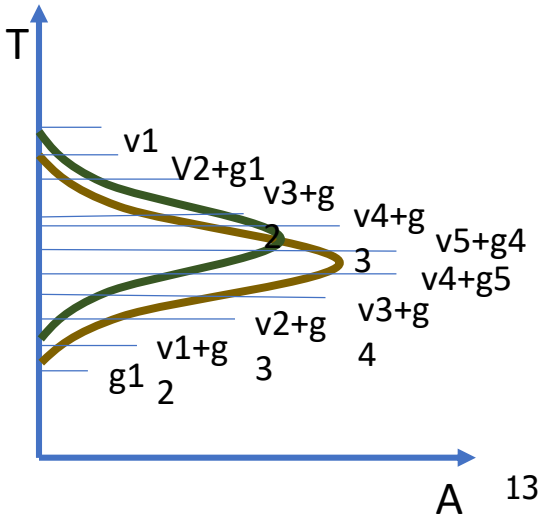
$$R_g = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

We used a half-Gaussian fitting method to derive the R_g

- ✓ assume the soil echo under zero height is pure
- ✓ the understory vegetation height is larger than the pulse time resolution (15 cm for 1 ns)



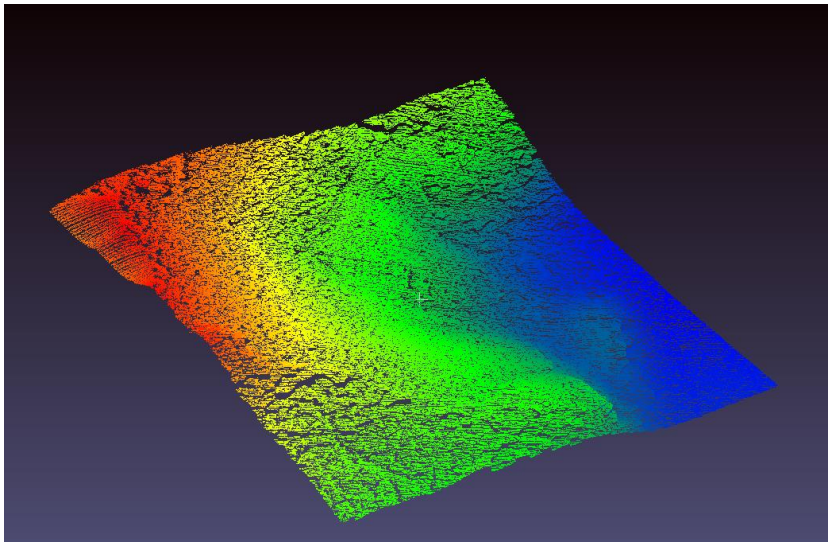


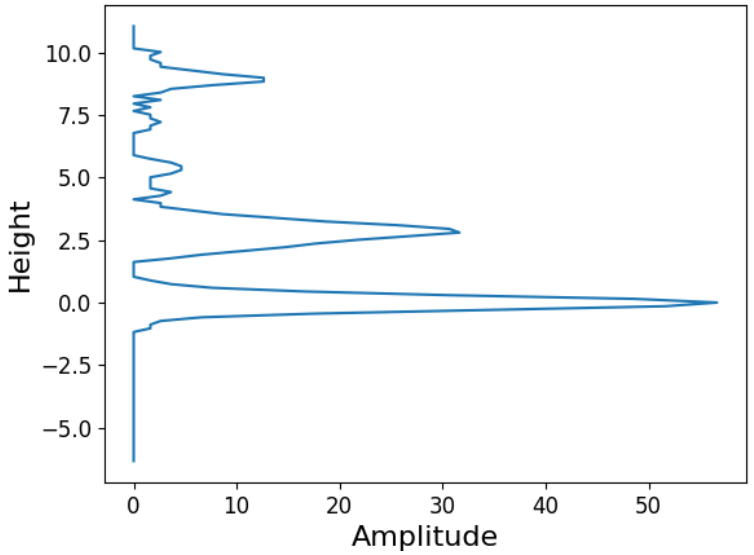


2 EDM model: solve the unknown parameters (R_m)

Height normalization for waveform

- ✓ extract the local maximum at the lowest height
- ✓ ground filter for the local maximum points using CSF filter
- ✓ implement height normalization for the whole waveform
- ✓ use a height threshold to separate upper (R_c) and lower layer (R_m)





2 EDM model: solve the unknown parameters (P_o)

The derivation of P_o is given by

$$P_o = 1 - \frac{R_c}{R_v} * \frac{1}{1 + \frac{R_g}{R_v} * \frac{\rho_v}{\rho_g}}.$$

- ✓ assume the backscattering coefficients of both overstory and understory vegetation are identical
- ✓ the term ρ_v refer to the global backscattering coefficient for vegetation

The ratio ($\frac{\rho_v}{\rho_g}$) can be derived by a linear regression

$$R_v = -\frac{\rho_v}{\rho_g} R_g + J_0 \rho_v$$

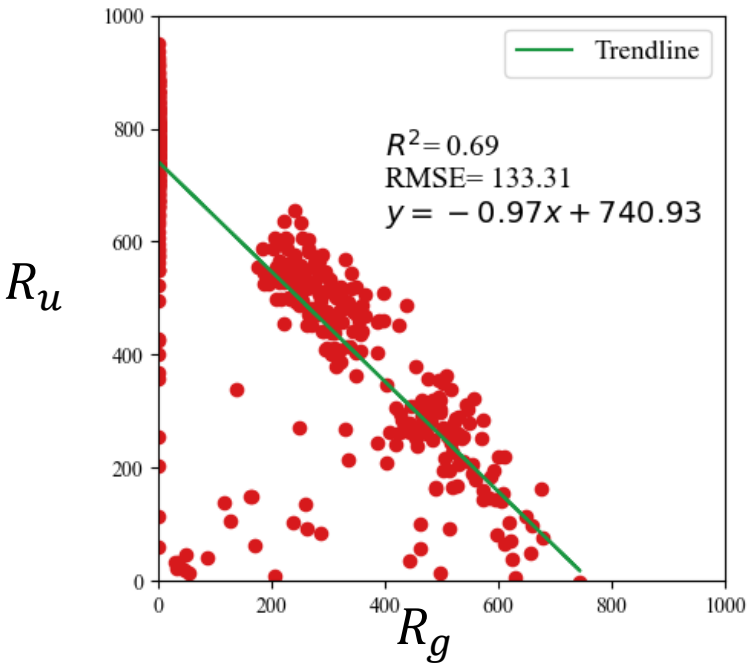
2 EDM model: solve the unknown parameters ($J_0\rho_u$)

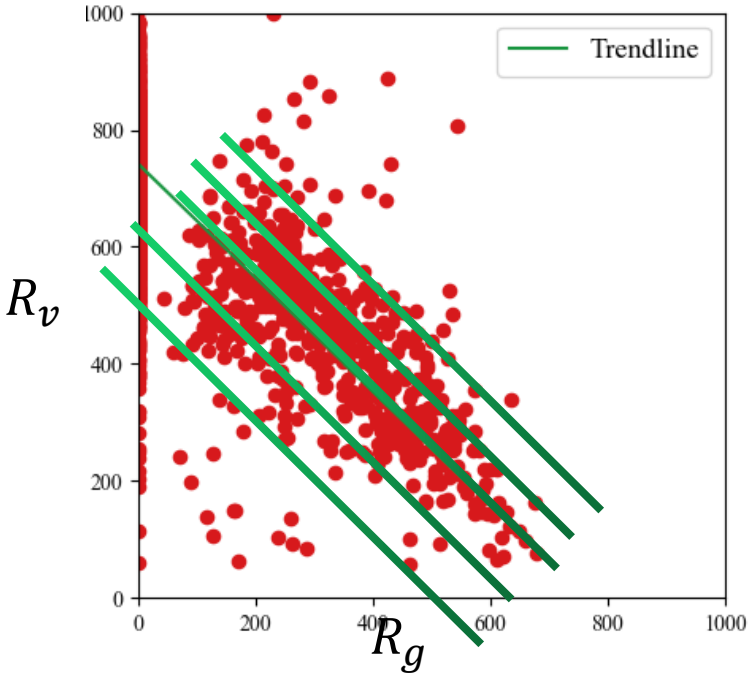
- The endmember ($J_0\rho_u$) can be derived by a linear regression

$$R_u = -\frac{\rho_u}{\rho_g} R_g + J_0\rho_u$$

- Endmember variability shall be considered

$J_0\rho_u$, $J_0\rho_u$, $J_0\rho_u$, $J_0\rho_u$, …

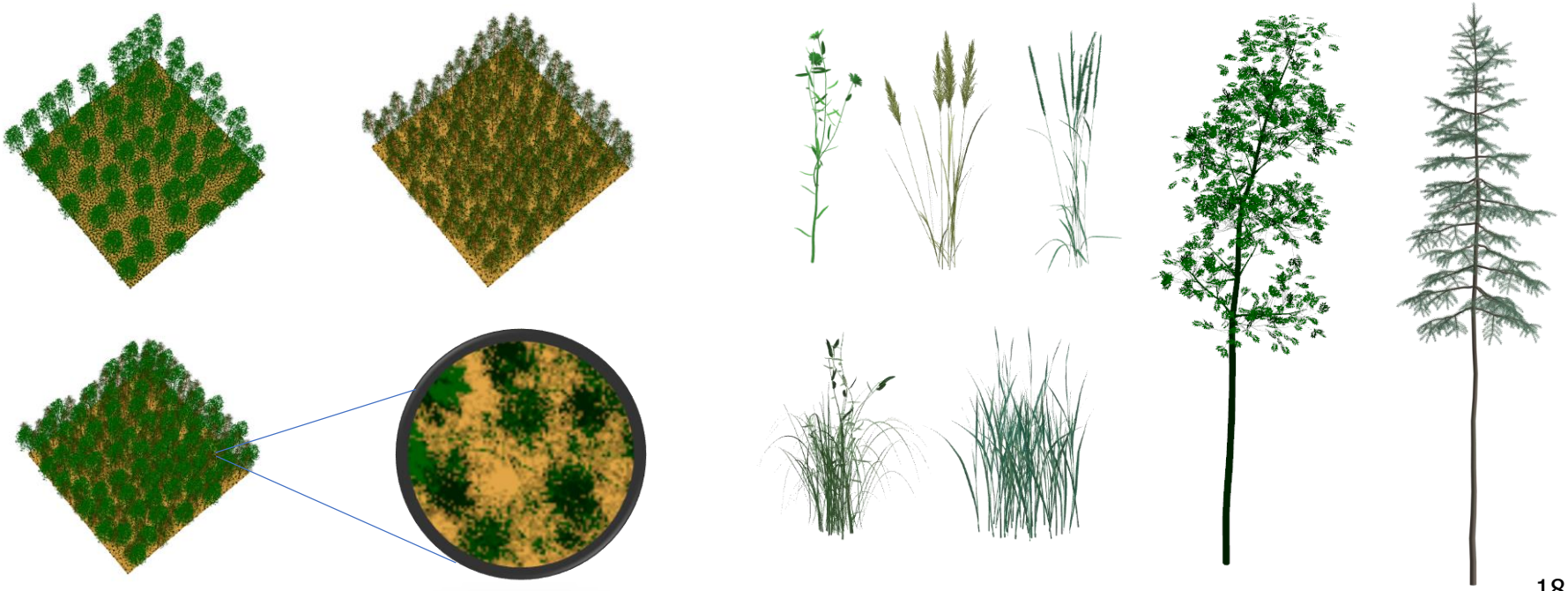




We need data to test it.

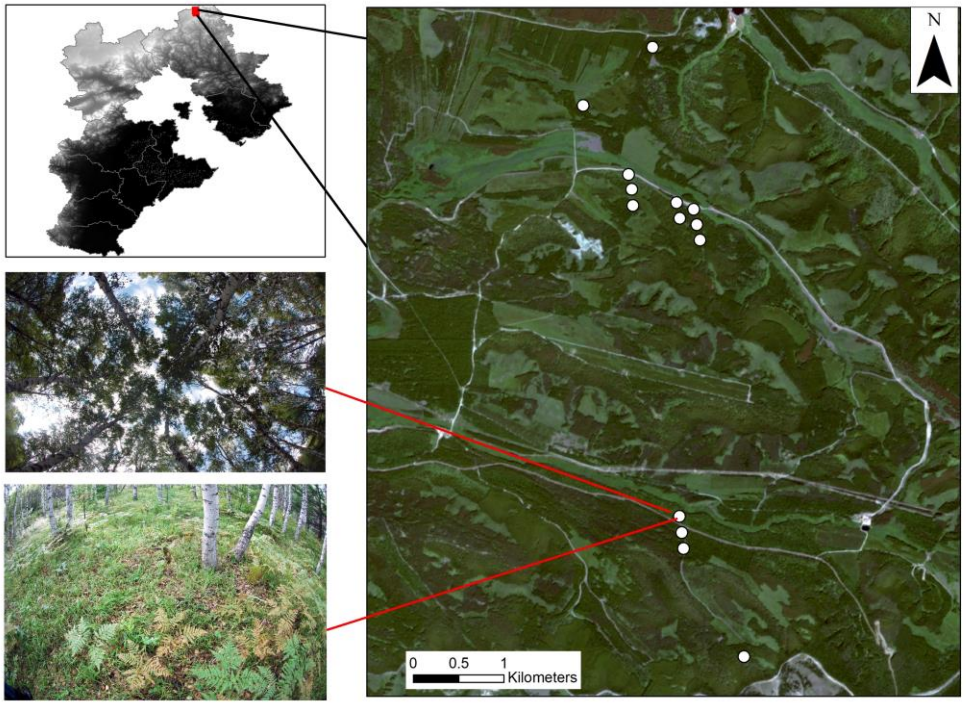
A range of virtually realistic forest scenarios

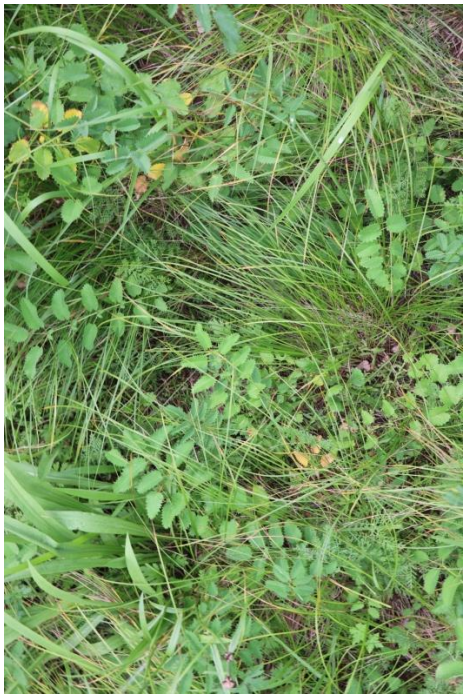
- ✓ sparse, mediate and dense plots for broadleaf, coniferous and mixed forest (3×3)
- ✓ spatial variation of understory vegetation cover
- ✓ waveform and point cloud simulation by LESS model



Boreal forest in Sanhanba National Forest Park

- ✓ footprint size =25 cm, calibrated waveform
- ✓ field survey of understory gap fraction
  - digital camera and image segmentation





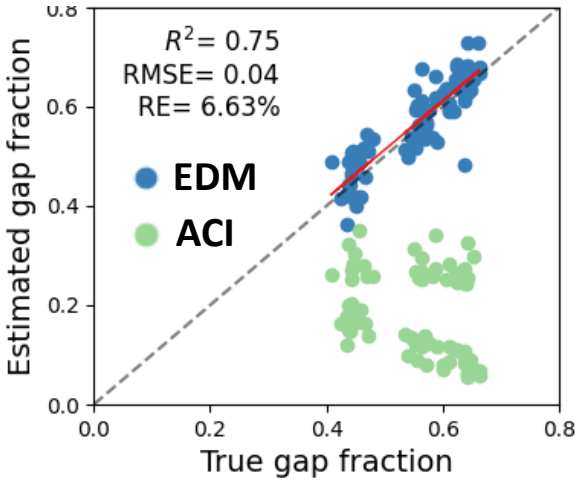
Let’ s see the evaluation of EDM.

4 Evaluation based on synthetic data

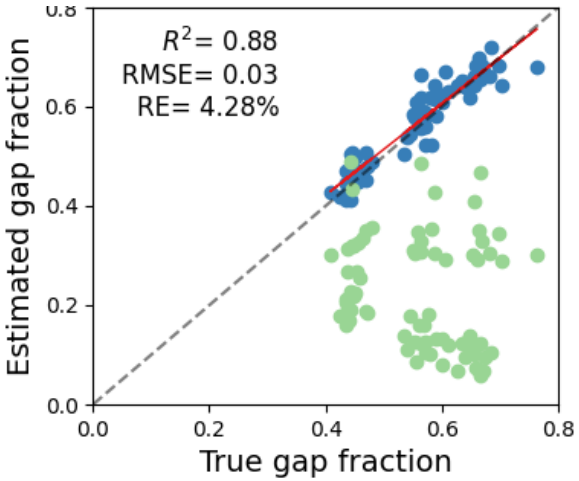
■ Understory gap fraction

- ✓ EDM highly improved the retrieval accuracy compared to return-number-based method (i.e., using point clouds) (RMSE<0.05)
- ✓ **EDM is not sensitive to the overstory occlusion**, the return-number -based method depends on the overstory conditions

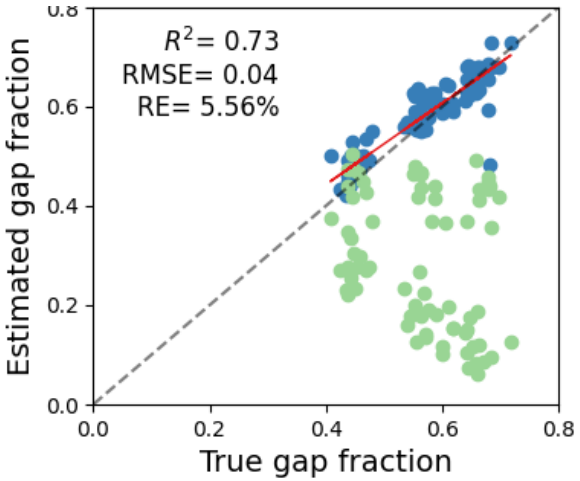
dense forest



mediate forest



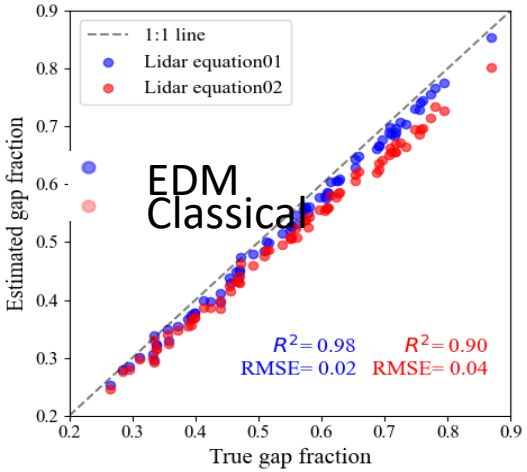
sparse forest

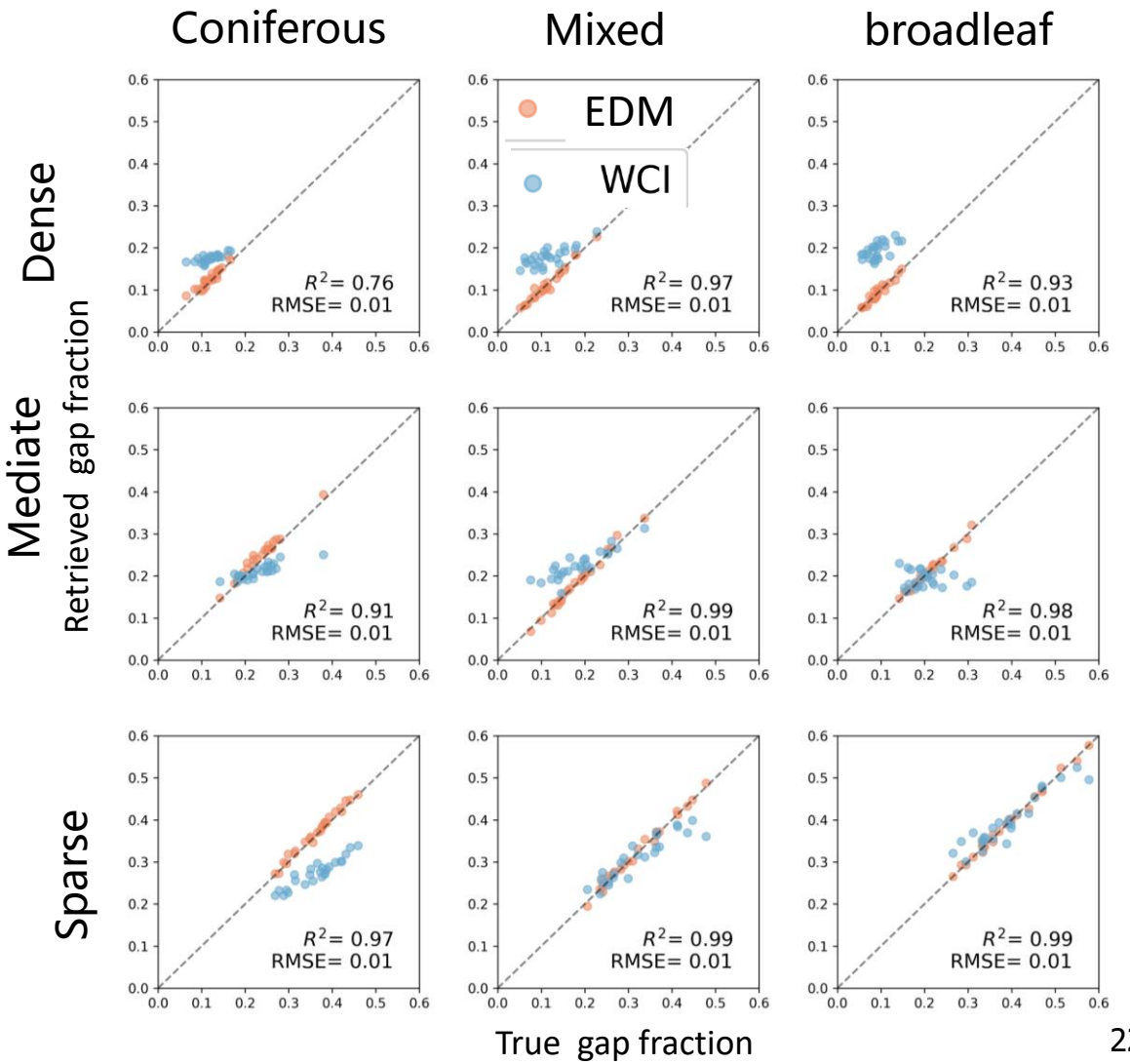


4 Evaluation based on synthetic data

■ Overstory gap fraction

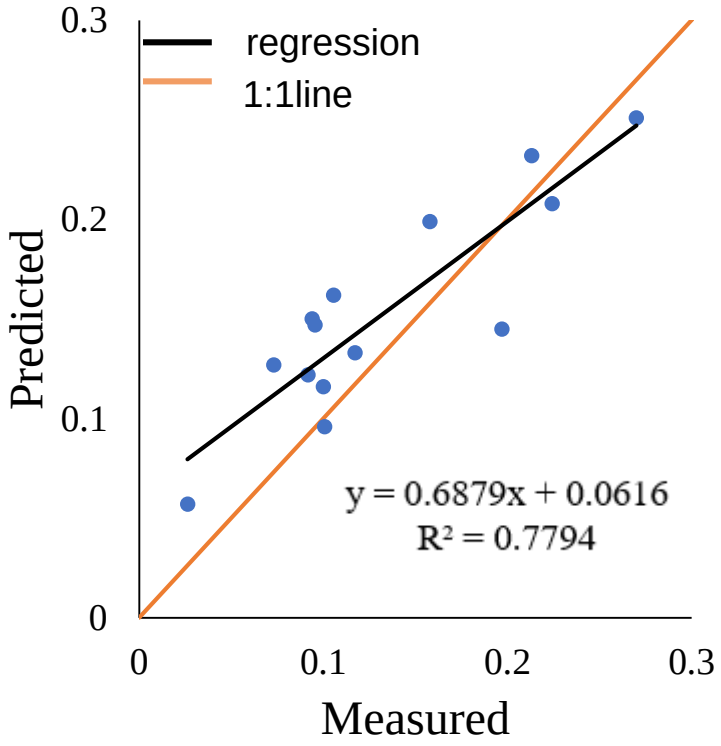
✓ EDM shows slightly better than the classical method and much better that return number based method

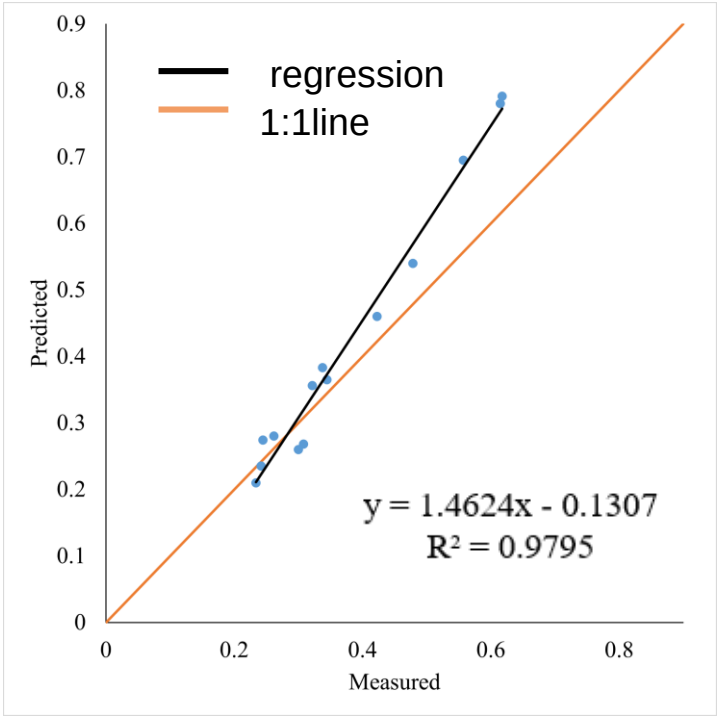




4 Evaluation based on real data

- ✓ For understory gap fraction, EDM outcomes have good consistency with field measurements
- ✓ For overstory gap fraction, EDM seems overestimated but maybe due to the "fake-truth"





What’ s the next step ?

5 Next step

- Possible test in temperate and tropical forests
- Analysis of slope effect even for small-footprint
- Thinking the possibility of retrieval by satellite

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感谢您的倾听! 提问?
Thank you! Questions?

Linyuan Li

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