



SCIENCE AND
EDUCATION **FOR**
SUSTAINABLE
LIFE

Sensitivity of TanDEM-X to Vertical and Horizontal Boreal Forest Structure Using IWCM

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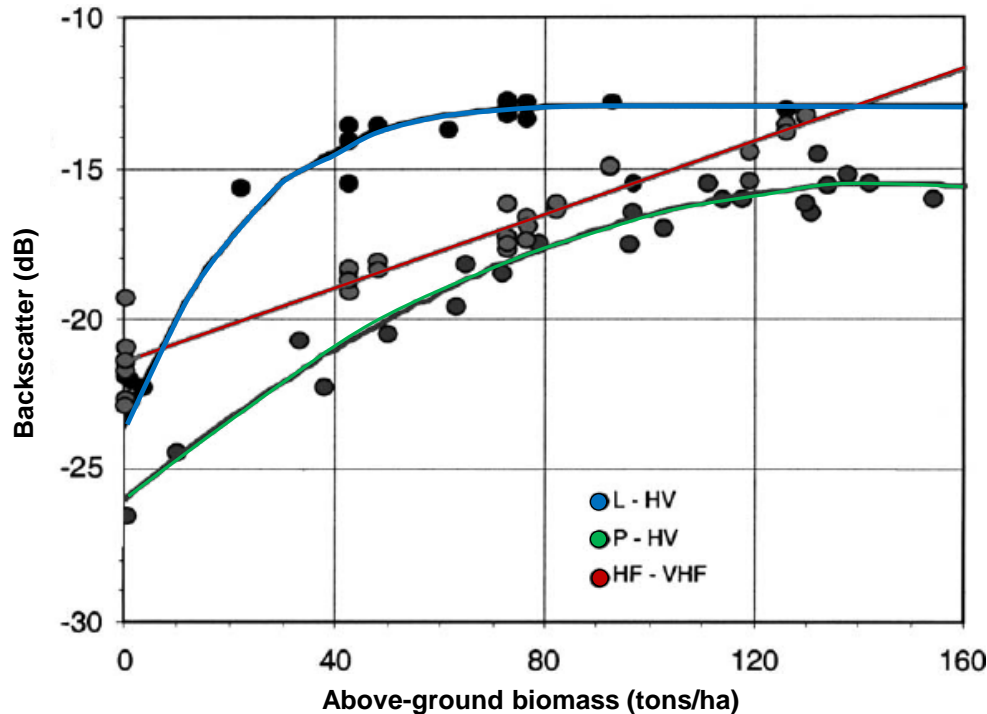
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Introduction

- Backscatter
- Interferometry
- Coherence amplitude inversion
- Phase height for forest mapping
- Some InSAR models



Backscatter vs. AGB saturates for shorter wavelengths



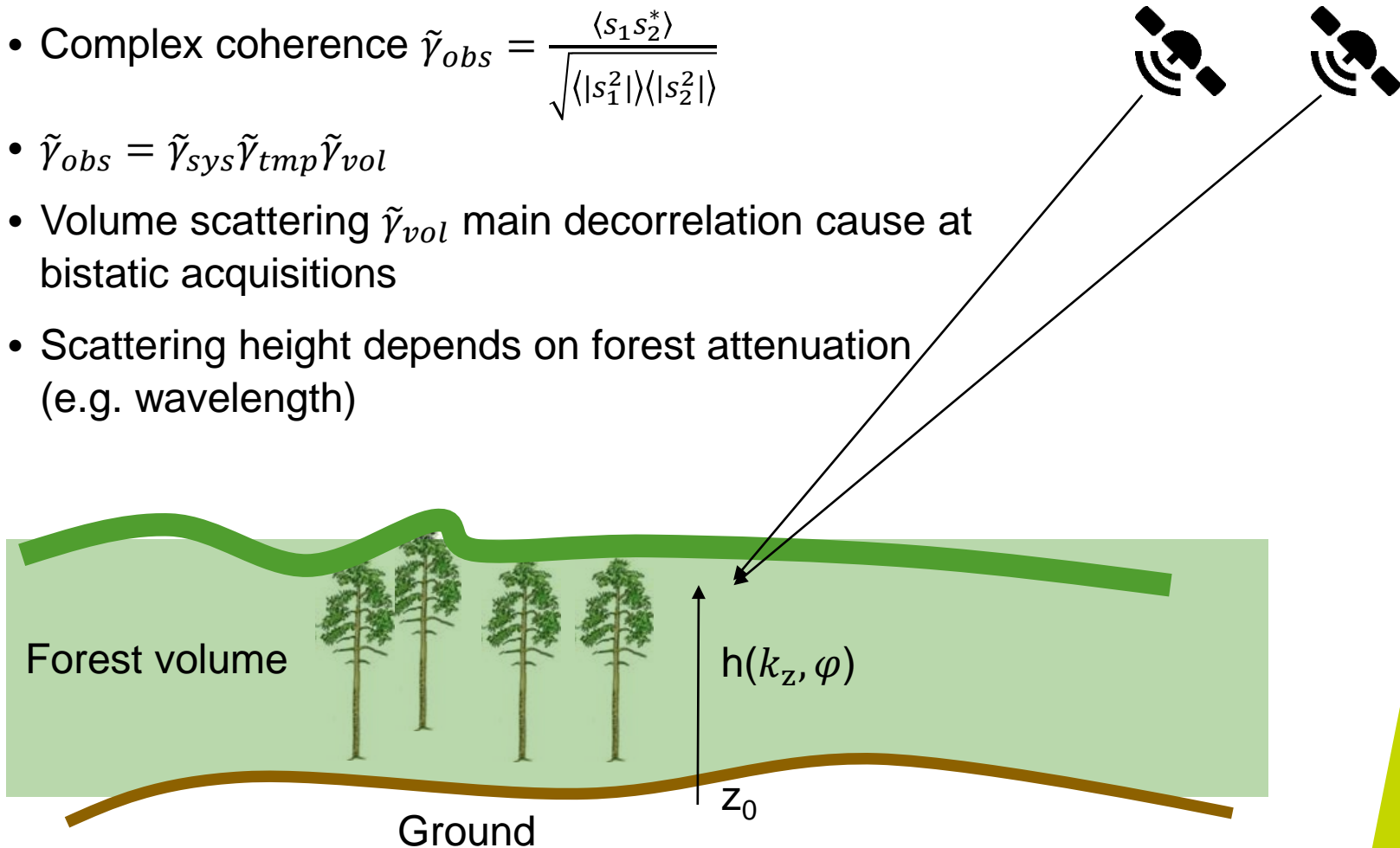
Note: This graph shows the saturation of SAR backscatter from the L-band (blue top line), P-band (green bottom), and VHF-band (red, middle) over a forest in Landes, France. In this study, L- and B-band sensitivity to increasing biomass is limited after 100 tons/ha; other studies have achieved higher sensitivity by combining polarizations. *Source:* Le Toan et al. 2004

$$\varphi = \arg(\tilde{\gamma})$$

$$\gamma = |\tilde{\gamma}|$$

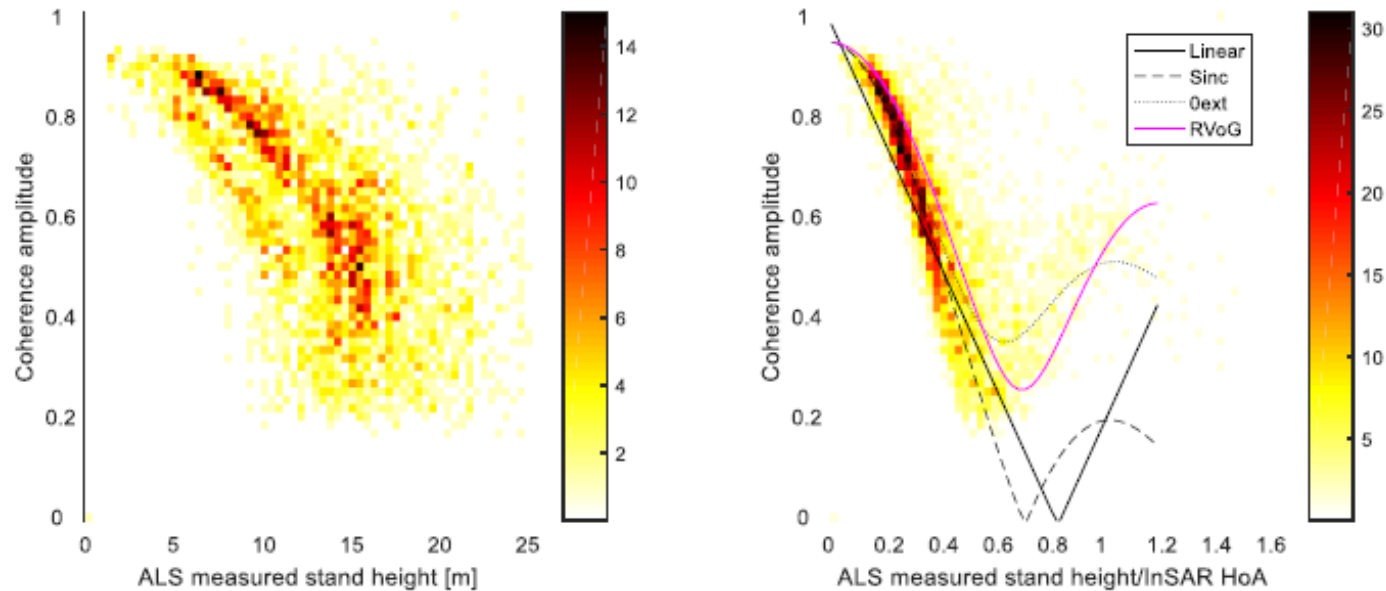
Interferometry

- Complex coherence $\tilde{\gamma}_{obs} = \frac{\langle s_1 s_2^* \rangle}{\sqrt{\langle |s_1^2| \rangle \langle |s_2^2| \rangle}}$
- $\tilde{\gamma}_{obs} = \tilde{\gamma}_{sys} \tilde{\gamma}_{tmp} \tilde{\gamma}_{vol}$
- Volume scattering $\tilde{\gamma}_{vol}$ main decorrelation cause at bistatic acquisitions
- Scattering height depends on forest attenuation (e.g. wavelength)



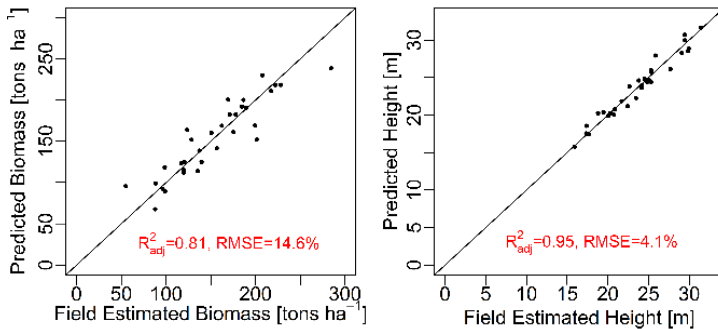
Coherence amplitude inversion

- Stand height vs. coherence amplitude relevant for forest mapping where no terrain model is available
- HoA important for sensitivity

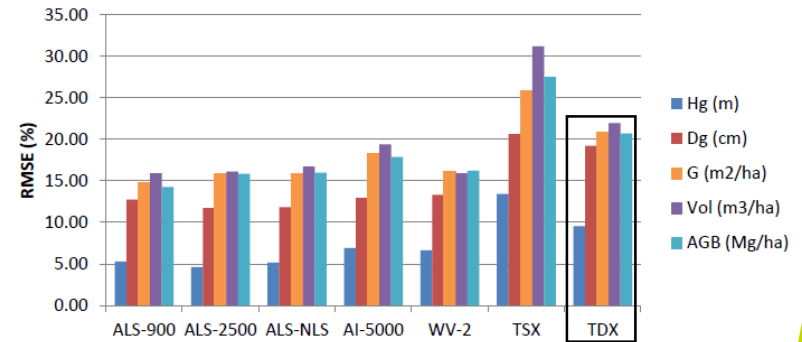


Phase height for forest mapping

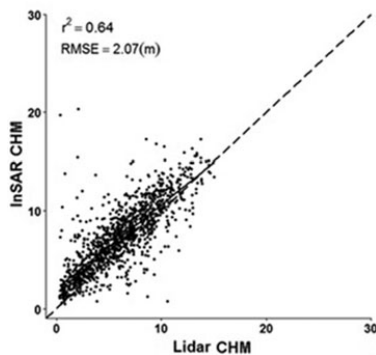
- Phase height a good predictor for height and biomass with proper scaling. $AGB = \alpha_1 \varphi / k_z$



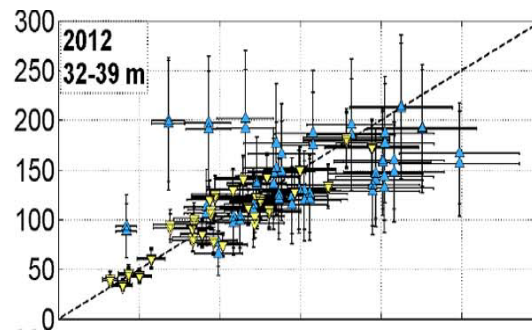
Persson and Fransson, 2017



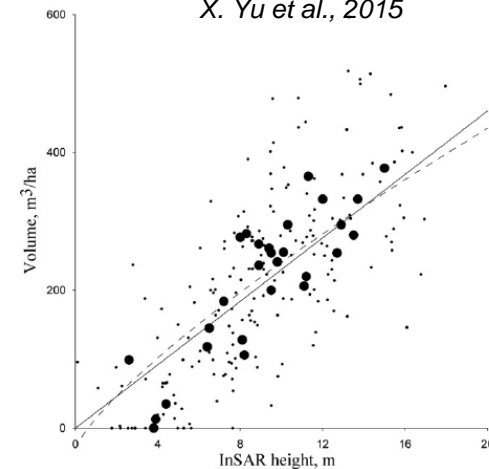
X. Yu et al., 2015



Y. Sadeghi et al., 2017



Soja, Persson and Ulander, 2015



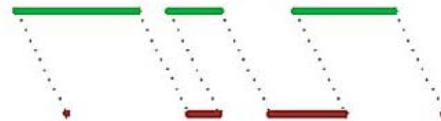
S. Solberg et al., 2013

Some InSAR models of forest

- Models using the complex coherence $\tilde{\gamma}$, both coherence and phase
- Volume scattering $\tilde{\gamma}_{vol}$ often assumed as main decorrelation source
- $\tilde{\gamma}_{vol}$ modelled as the normalized Fourier transform of the vertical distribution $F(z)$ of scatterers (some vertical scattering profile)
- Without fully polarimetric data some parameters might have to get fixed, by using ancillary data or simplifying the model
- E.g. Random Volume over Ground (RVoG) and Two-level model (TLM)



RVoG



TLM

Interferometric Water Cloud Model (IWCM)

J. Askne et al., 1997



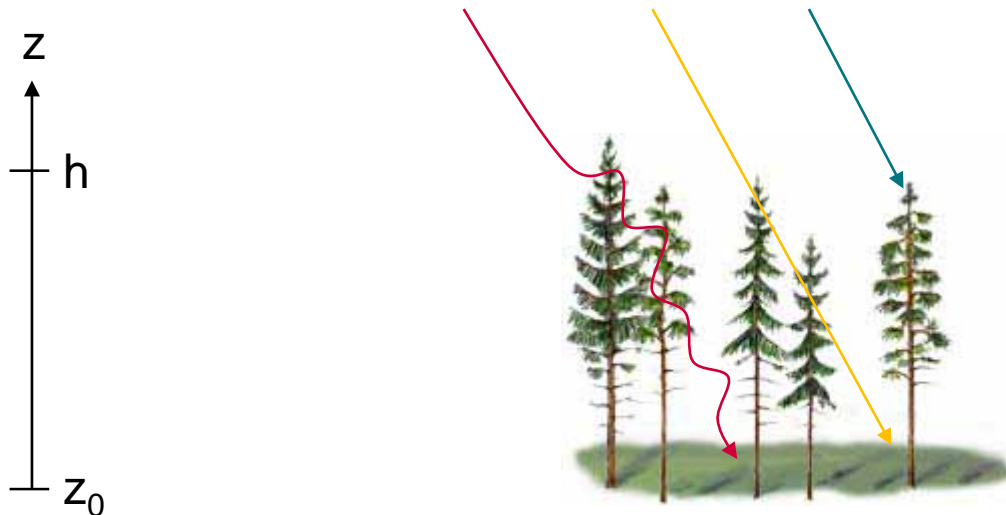
What causes scattering in the forest?

IWCM assumes

- Vertical backscatter intensity profile:

$$\sigma(z) = \sigma_{\text{gr}}^0 [(1 - \eta) + \eta e^{-\alpha h}] \delta(z) + \sigma_{\text{veg}}^0 \eta \alpha e^{-\alpha(h-z)} H(h - z) H(z)$$

- IWCM consists of 4 parameters: $\alpha, \sigma_{\text{gr}}^0, \sigma_{\text{veg}}^0, \gamma_{\text{sys}}$ for the area
- and two unknowns (forest height h and area-fill η) for each pixel



$$\tilde{\gamma}_{rv}(k_z) = \frac{\alpha}{\alpha + ik_z} \frac{e^{ik_z h} - e^{-\alpha h}}{1 - e^{-\alpha h}}$$

$$m = \frac{\sigma_{gr}^0}{\sigma_{veg}^0} \frac{1 - \eta(1 - e^{-\alpha h})}{\eta(1 - e^{-\alpha h})}$$

IWCM uses all observables

- Backscatter, coherence, and phase height are modeled based on the intensity profile $\sigma(z)$

- $\sigma^0(z) = \int_{-\infty}^{\infty} \sigma(z) dz$

- $\tilde{\gamma}_{vol}(k_z, \sigma_z) = \int_{-\infty}^{\infty} \frac{\sigma(z)e^{ik_z z} dz}{\sigma(z) dz} = \frac{m + \tilde{\gamma}_{rv}(k_z)}{m + 1}$, where

$\tilde{\gamma}_{rv}$ = random volume decorrelation, m = ground-to-volume ratio

- coherence = $|\gamma_{sys} \tilde{\gamma}_{vol}|$

- phase height = $\arg(\gamma_{sys} \tilde{\gamma}_{vol}) / k_z$

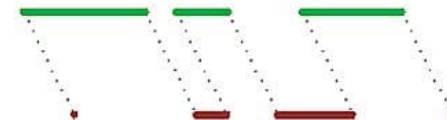


IWCM



RVoG

No term for gaps

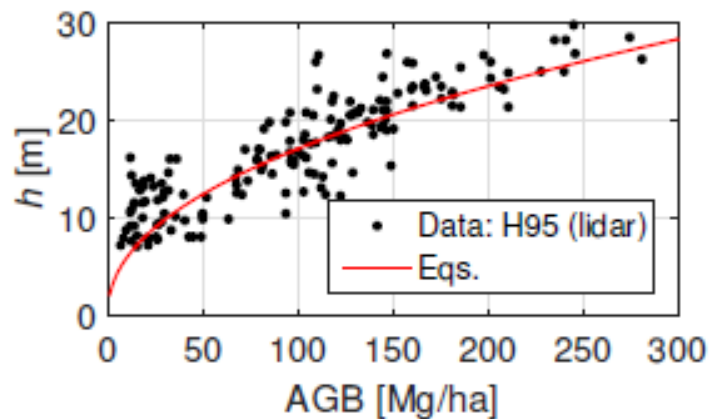


TLM

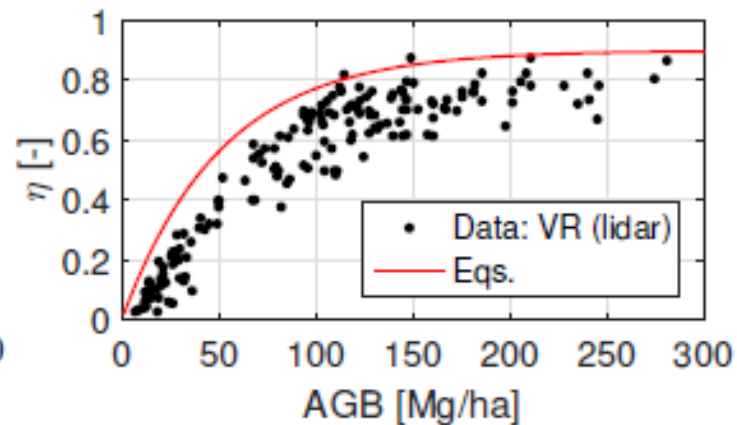
$\alpha = \infty$

IWCM volume, height and density relations

- Each observable contributing where it is sensitive to the forest
- When using TanDEM-X data, phase height is the most contributing variable; sensitive to the full volume spectrum
- Allometric equations used to express volume (AGB) in terms of forest height h and density η :



$$h(V) = (2.44V)^{0.46}$$



$$\eta(V) = 0.9(1 - e^{-0.01V})$$

Solving IWCM

- The cost Δ w.r.t. the 4 parameters for each observable defined as RMSE
- Total cost is minimized using numerical non-linear optimization

$$\Delta_{\sigma} = \sqrt{\frac{(\sigma_{IWCM} - \sigma_{Obs})^2}{n}} \quad \Delta_{\gamma} = \sqrt{\frac{(\gamma_{IWCM} - \gamma_{Obs})^2}{n}} \quad \Delta_h = \sqrt{\frac{(h_{IWCM} - h_{Obs})^2}{n}}$$

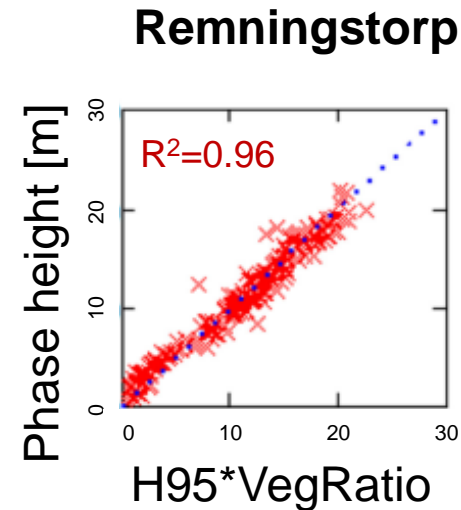
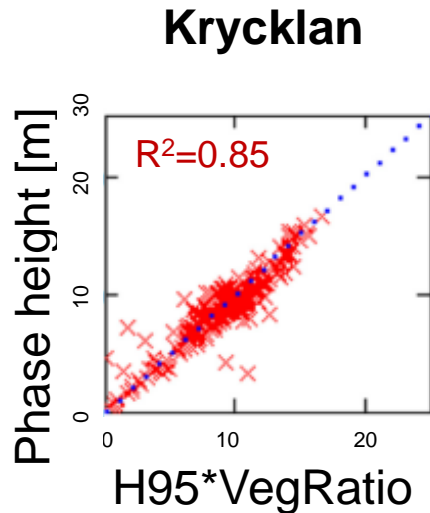
$$\Delta_{Tot} = \frac{\Delta_{\sigma} \Delta_{\gamma} \Delta_h}{\Delta_{\sigma} \Delta_{\gamma} + \Delta_{\gamma} \Delta_h + \Delta_{\sigma} \Delta_h}$$

How is IWCM affected by changes in forest height and density?

- Height and density in ALS data
- Phase height vs. ALS
- Case study from Swedish test site
- Classifying forest types



Relation of phase height to ALS metrics



Analyses have showed that the phase height is equally sensitivite to changes in height and density

(On the Sensitivity of TanDEM-X-Observations to Boreal Forest Structure. Askne, Persson and Ulander, 2019)

Case study

On the Sensitivity of TanDEM-X-Observations to Boreal Forest Structure. *Askne, Persson and Ulander, 2019*

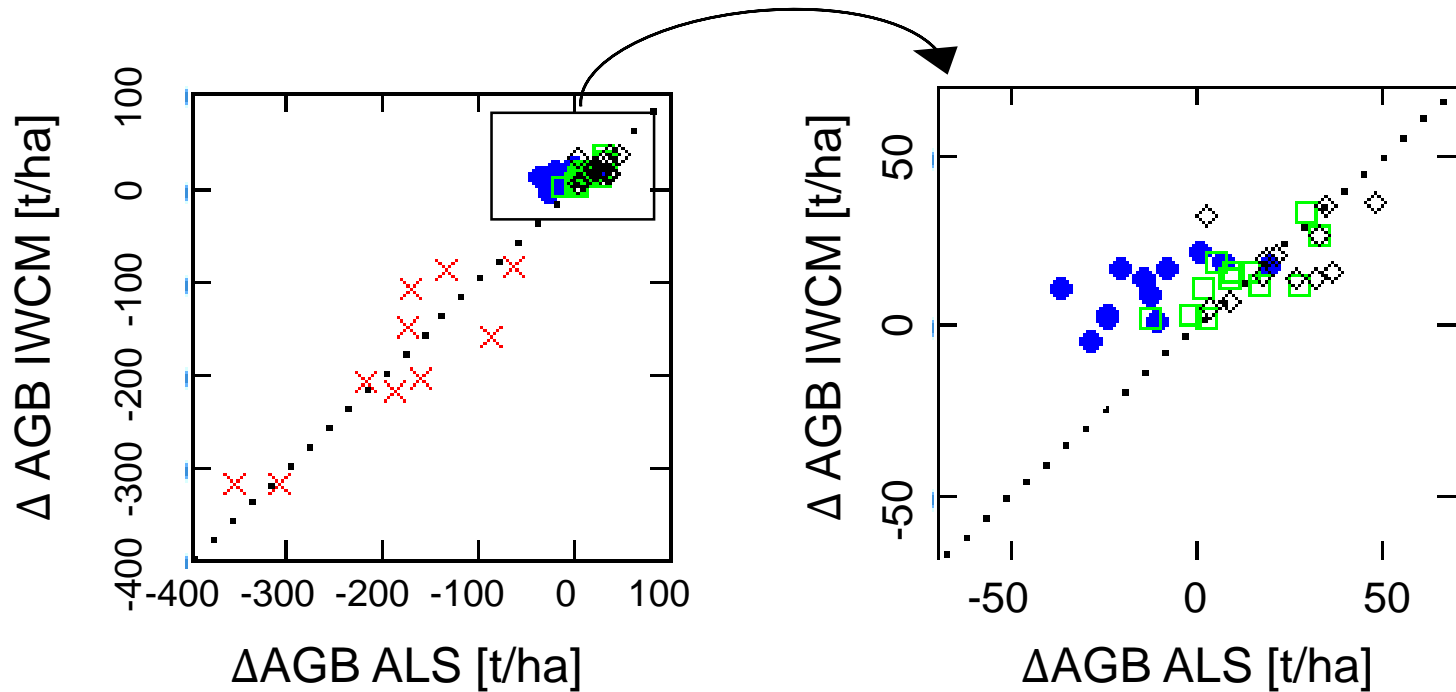
- Remningstorp
- Stands with clear-cut, commercial thinning, (pre-commercial) thinning and no changes selected from management plan
- Fortyeight 30m radius circular plots manually distributed in the 4 classes
- ~200 field plots w 10m radius together with ALS data used to generate AGB maps for 2010 and 2014 respectively
- No error in phase height assumed cost →

(due to very strong relation to AGB in previous slide)

$$\frac{1}{\Delta_{Tot}} = \frac{1}{\Delta_{\sigma}} + \frac{1}{\Delta_{\gamma}}$$



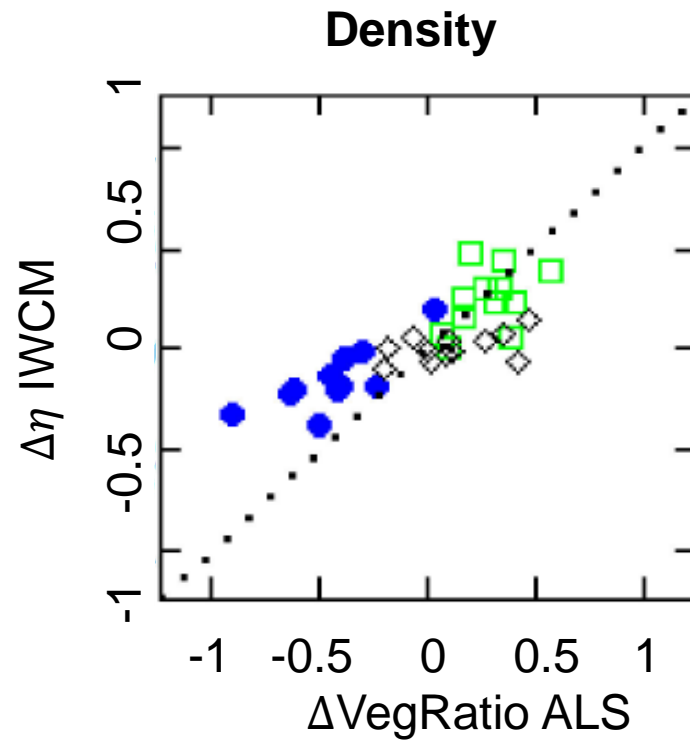
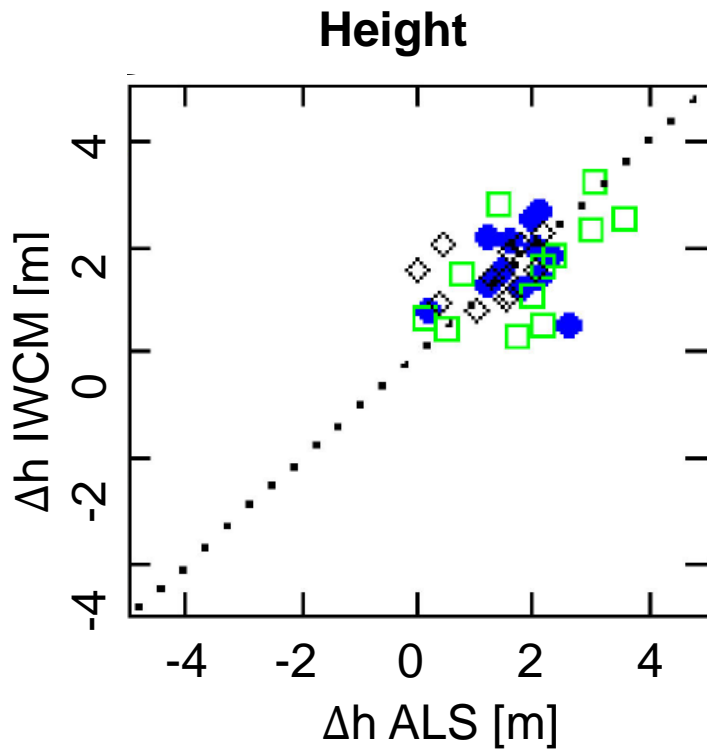
IWCM AGB changes due to forest changes



- Commercially thinned
- × Clear-cut
- Pre-commercially thinned
- ◇ No changes



Partitioned differences due to forest changes



- Commercially thinned
- Pre-commercially thinned
- ◇ No changes

- × Clear-cut
- △ Clear-cut with seed trees left



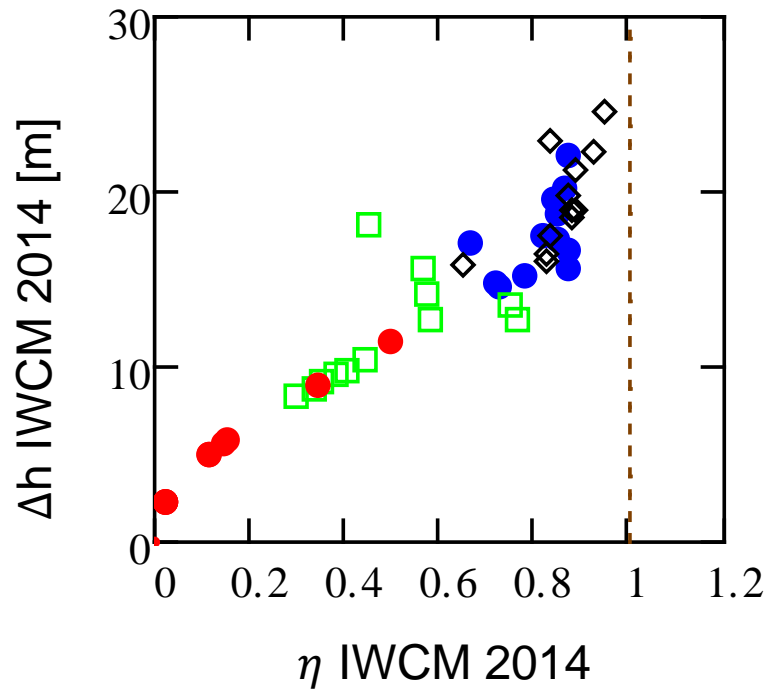
Quantification of changes 2010 - 2014

Class	AGB range t/ha	Δh [m] IWCM	$\Delta H95$ [m] ALS	Δ Area-fill IWCM	Δ VR ALS	Δ AGB t/ha IWCM	Δ AGB t/ha ALS
No change	84 – 360	1.5	1.2	0	0.04	19.8	23.3
Pre-comm. thinned	17 – 109	1.7	1.9	0.09	0.11	13.7	10.9
C.thinned	70 – 230	1.7	1.7	-0.06	-0.18	10.5	-13.2
Clear-cut	0 – 369	-15.4	-17.9	-0.59	-0.64	-169.5	-170.1

- Height changes covered well with TanDEM-X
- The wavelength and incidence angle constrain the perception of ground contributions, which delimits determination of area-fill
- The errors increase for low phase heights → use phase height > 5m for improved accuracy

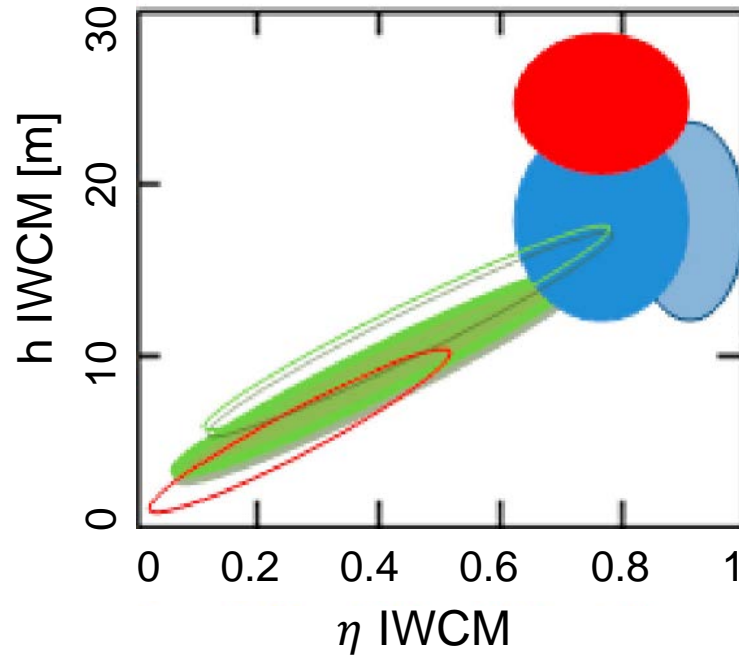


Classification of forest types with h and η



- Commercially thinned
- Pre-commercially thinned
- Clear-cut
- ◇ No changes

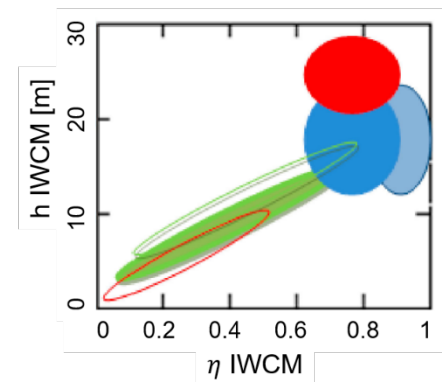
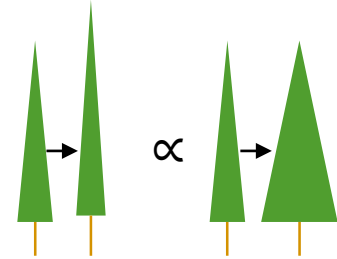
Classify forest types with h and η



- Ready to clear-cut
- Ready for commercially thinning
- Ready for pre-commercially thinning
- After actions

Conclusions

- Forest changes due to manual actions can be detected reasonably well using TanDEM-X data and IWCM
- The phase height is sensitive to relative changes in both forest height and canopy density (when the references ALS H and ALS VegRatio are used)
- The combined information of both height and density can be used to classify different forest types and hence automatically identify the need for forest actions



Thank you!

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