On the vertical distribution of backscatter from a forest canopy: a macroecological approach

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What I’m going to talk about…

• The importance of vertical structure
• Some examples of assumed vertical structure
• A simplified model of vertical structure using a macroecological model
“Vegetation structure”

- A recent review paper [McElhinny et al., 2005] lists 35 different forest attributes that have been used by forest ecologists and foresters to characterise “forest structure” in the literature…
- …plus a further 12 indices that have been used to specifically quantify stand “structural complexity”.

• Height, and variation of height, of the overstorey
  
  – “It is an attribute, which is readily derived from [optical] remotely sensed data, and can be indicative of successional stage, the number of strata, and stand biomass.”
Stand height vs stand biomass

Biomass = a \cdot h^\alpha

Courtesy of Tobias Mette, DLR
Vertical profile… of what?

Fig. 6 Modelled needle area distribution per metre height interval (triangles Norway spruce, circles Scots pine, thick line total needle area)

Morén, Lindroth, Flower-Ellis, Cienciala and Meelis Mölder
Fig. 8. Vertical backscatter profiles using the real scattering area correction (solid line) and the infinite layer hypothesis (dotted line). Results are presented for X-band at VV polarization for a 40-year old Austrian pine at 3° incidence.

Links to process models

• POLinSAR models don’t “talk the same language” as process/plant models. There is no biology in…
  – Water cloud model
  – Random volume over a ground surface
  – Oriented volume over a ground surface
A general structure model

West, Brown & Enquist
A general model for the structure and allometry of plant vascular systems.

Why is it interesting?

Processes, distribution of resources, leaf area, age.
Biomass partition (incl roots) and
Branches are cylinders!
(model gives size and number density)
The “pipe model” (area preserving)
Radiative transfer modelling (RT2): homogenous layers of scatterers
Rayleigh Scattering only

\[ \sigma_{Rayleigh} \propto N_k v_k^2 \]

\[ = r_0^2 r_k^{(12\alpha-2)/3\alpha} \]

\[ \sigma_{k, Rayleigh} \propto n_k^{-k(6\alpha-1)/3} \]
Backscatter as a function of branching level (Rayleigh only)

Theoretical for 3 different scaling parameters

- RT2 HV backscatter $a=2/3$
- Rayleigh backscatter (arbitrary units)
- Rayleigh $a=2/3$
- Rayleigh $a=4/3$

RT2 Modelled (P-band)
Optical Scattering

\[ \sigma_{k,\text{Optical}} \propto N_k A_k \]

\[ = N_k r_k \ell_k \]

\[ = r_0^{2/a} r_k^{(3a-4)/3a} \]

\[ \propto n^{k(4-3a)/6} . \]
Backscatter as a function of branching level:

- **RT2 HV backscatter**
  - $a = \frac{2}{3}$
- **RT2 HV backscatter**
  - $a = 1$
- **Rayleigh backscatter**
  - $a = 1$ (arbitrary units)
- **Optical backscatter**
  - $a = \frac{2}{3}$
- **Optical backscatter**
  - $a = \frac{2}{3}$
- **Rayleigh backscatter**
  - $a = \frac{4}{3}$
- **Rayleigh backscatter**
  - $a = \frac{4}{3}$
- **Optical backscatter**
  - $a = \frac{4}{3}$
- **Optical backscatter**
  - $a = \frac{4}{3}$
Backscatter (per unit height) as a function of height

- Height (m)
- Backscatter of level (dB)

- Rayleigh $a=1$
- Optical $a=1$
- Exp
- RT2 HV for $a=1$
Is this always the case?
ICESat (from Hancock and DiMarzio)

http://radiation.nsidc.org/events/eos_workshop04/presentations.html

Three Representative Return Pulse Waveforms

- Low canopy closure
- High canopy closure
- High canopy closure

Height Above Ground (m)
Is this always the case? No!
Conclusions

- Vertical structure is important.
- Model predicts profile is not exponential for Rayleigh, but is for “optical” scatterers.
- For even-sized stands: expect clear vertical profile.
  - retrieval constraint function in PCT?
- Understorey usually exists.
- Tropical forest have more variability in height.
- Q: how to include orientation?
\[ \begin{align*}
&\text{Ordered volume} \\
&\text{Random volume}
\end{align*} \]
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Fig. 7. Comparison between the measured and calculated values of the backscattering cross section for coniferous twigs as a function of the scatterer radius.

Mougin et al (1993)
Branching network

\[ r_{k+1} = r_k n^{\frac{-a}{2}} \]

\( a \) is scaling parameter; \( a=1 \) is the pipe model
Lin and Sarabandi, IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 37, NO. 1, JANUARY 1999

Fig. 6. Visual verification of the fractal model: (a) photograph of the test maple stand, (b) the generated fractal tree without and (c) with leaves, and the calculated extinction profile (d).
Backscatter as a function of branching level

Reduction in Rayleigh scattering dominates over increasing number density

Increase in optical cross-section not sufficient to compensate for reduction in number density

Dominant scattering layer (i.e. particular size dominates, as standard interpretation predicts)
Biomass density vs backscatter saturation

Saturation
Saturation: The Water Cloud Model Explanation

A patch of vegetation

Amount of "stuff" (AGB) vs. Intensity

Saturation
But do trees grow like that?

A patch of vegetation
Bushy canopies

Bulky stem

→ a →

a=1 is the pipe model
Summary

Linear response (?)

Non-linear response (?)

2x basal area = 2x backscatter
Rayleigh Scattering only

\[ \sigma_{Rayleigh} \propto N_k v_k^2 = r_0^{2/a} r_k^{(12a-2)/3a}. \]

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Optical Scattering

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