AirMOSS

Airborne Microwave Observatory of Subcanopy & Subsurface Mission

AirMOSS soil moisture retreival: From forest to backscatter to soil moisture

Sermsak Jaruwatanadilok, My-Linh Truong-Loï
and Sassan Saatchi
Jet Propulsion Laboratory
California Institute of Technology

USC University of Southern California

Goddard Space Flight Center

Harvard

MIT

Oregon State University OSU

Purdue University

USDA

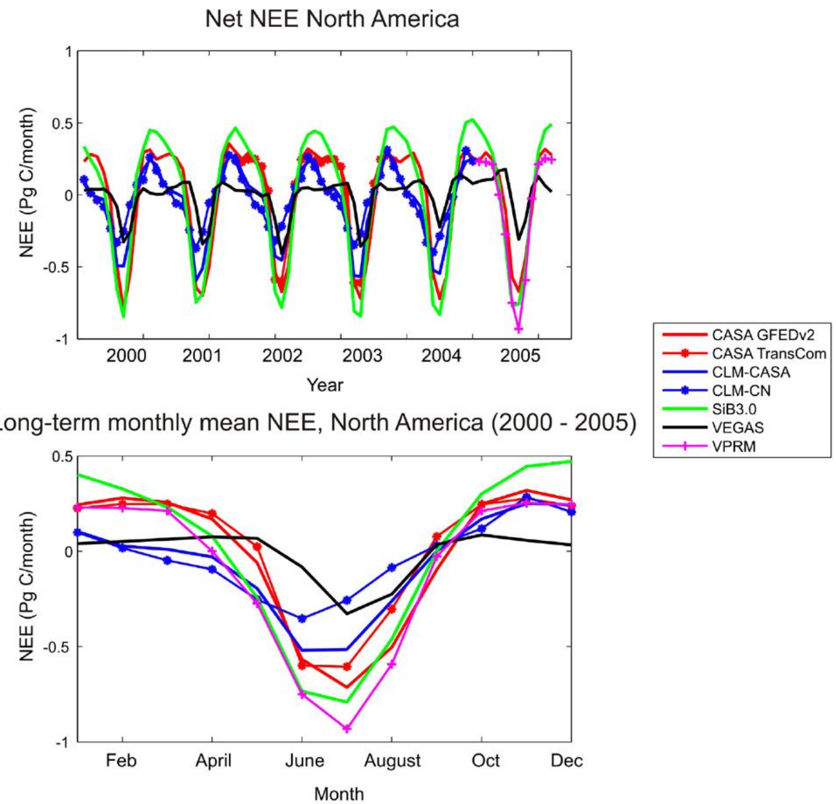
Venture

Outline

- Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) mission and objective
- From forest to backscatter
  - Derivation of parameters from FIA data: relationship of biomass with diameter at breast height (DBH), tree height, and tree diameter
  - Finding fit parameters
- From backscatter to soil moisture
- Field campaign

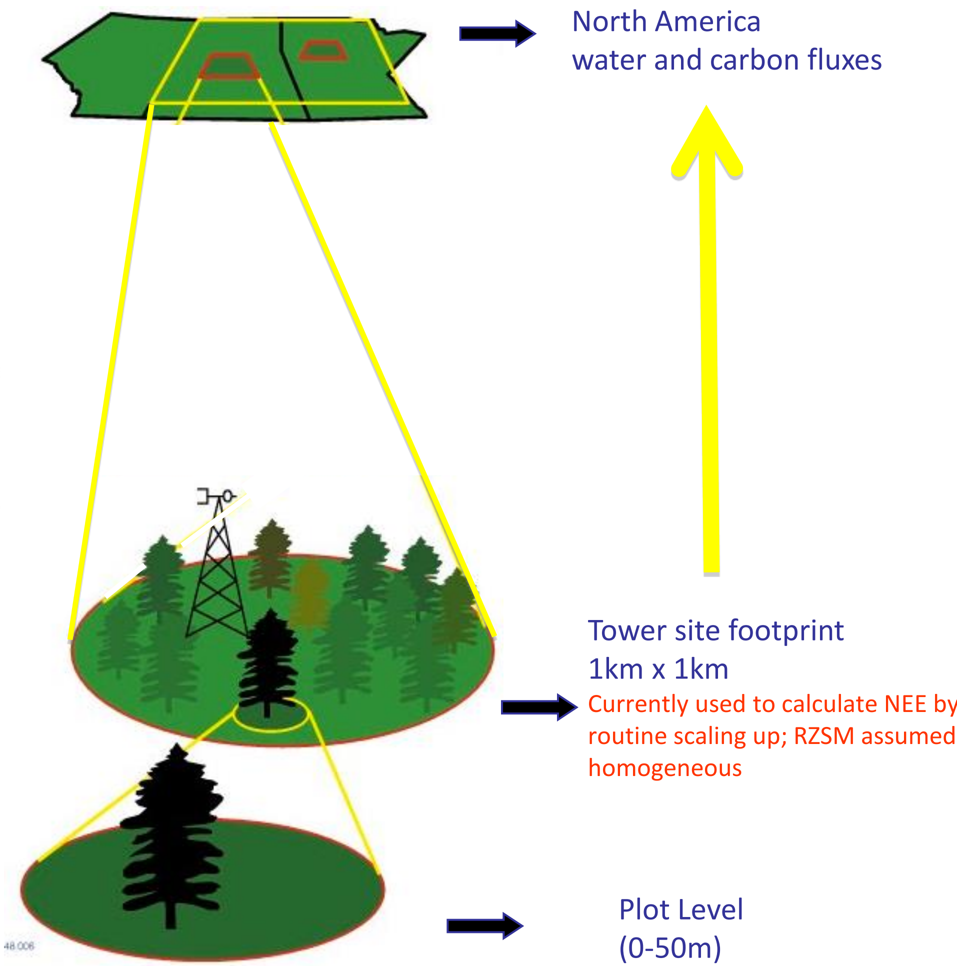
Scientific Approach (1)

Uncertainty in Annual and Seasonal Net Ecosystem Exchange Estimates over North America



Based on spatial resolution of ~ 0.5 degree

Bottom-up scaling



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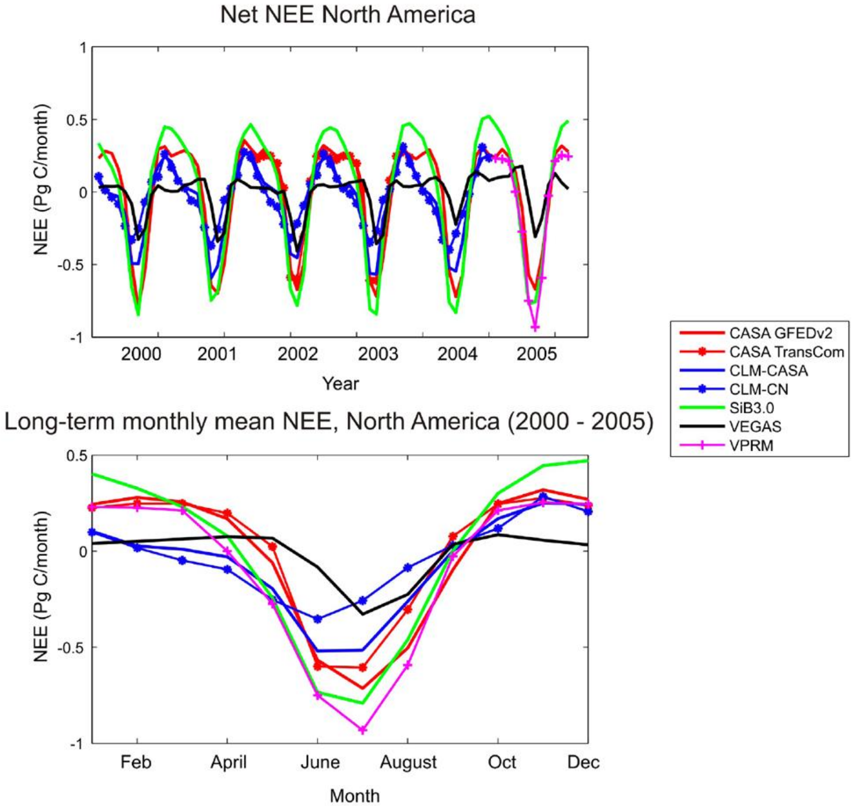
Scientific Approach (2)

Uncertainty in Annual and Seasonal Net Ecosystem Exchange Estimates over North America



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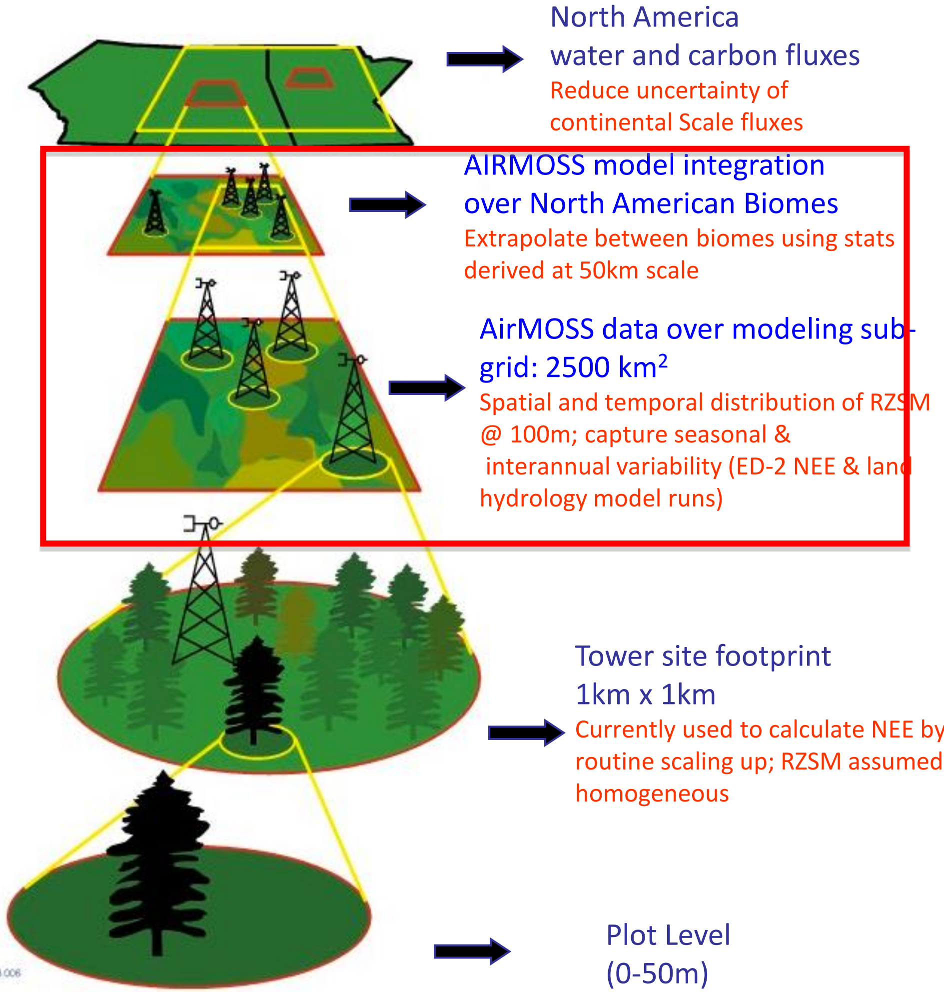
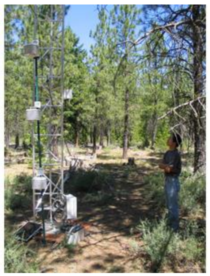


AirMOSS sites

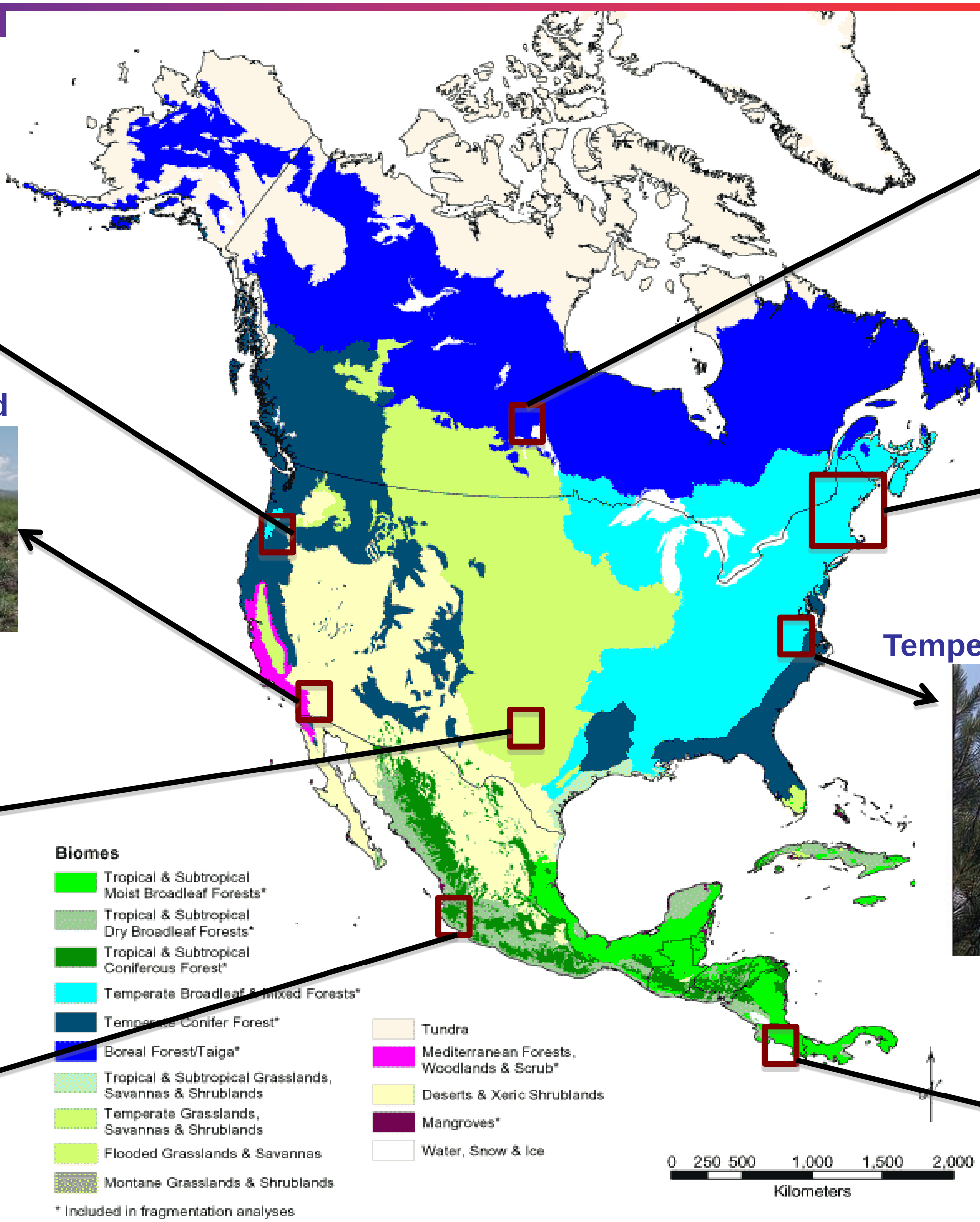
Temperate evergreen forest



Open shrubland

Temperate grasslands

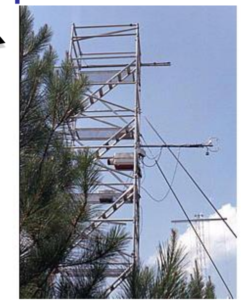
Subtropical dry forest



Boreal forest

Boreal transitional

Temperate mixed forest



Tropical moist forest

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Forward model expression

Distorted Born approximation model

$$\sigma^o_{pq} = \sigma^o_{pq\_direct} + \sigma^o_{pq\_doublebounce} + \sigma^o_{pq\_surface}$$

$$\sigma^o_{pq\_direct} = \sigma^o_{pq\_crown} + \sigma^o_{pq\_trunk}$$

$$\sigma^o_{pq\_doublebounce} = \sigma^o_{pq\_crown-ground} + \sigma^o_{pq\_trunk-ground}$$

$$\sigma^o_{pq\_crown} = \left(\rho_l \sigma_{pqld} + \rho_{b1}\sigma_{pqb1d} + \rho_{b2}\sigma_{pqb2d}\right)\left[\frac{1-\exp\left(-2\,\mathrm{Im}\{K_{pc}+K_{qc}\}d_c\right)}{2\,\mathrm{Im}\{K_{pc}+K_{qc}\}}\right]$$

$$\sigma^o_{pq\_trunk} = \left(\rho_t \sigma_{pqtd}\right)\left[\frac{1-\exp\left(-2\,\mathrm{Im}\{K_{pt}+K_{qt}\}d_t\right)}{2\,\mathrm{Im}\{K_{pt}+K_{qt}\}}\right]\exp\left(-2\,\mathrm{Im}\{K_{pc}+K_{qc}\}d_c\right)$$

$$\sigma^o_{pq\_surface} = \sigma^o_{pqg}\exp\left(-2\,\mathrm{Im}\{(K_{pc}+K_{qc})d_c + (K_{pt}+K_{qt})d_t\}\right)$$

$$\sigma^o_{pq\_crown-ground} = \left(\rho_l \sigma_{pqldr1} + \rho_b\sigma_{pqb1dr1} + \rho_{b2}\sigma_{pqb2dr1}\right) r_g \left|\Gamma_p\right|^2\left[\frac{1-\exp\left(-2\,\mathrm{Im}\{K_{qc}-K_{pc}\}d_c\right)}{2\,\mathrm{Im}\{K_{qc}-K_{pc}\}}\right]$$

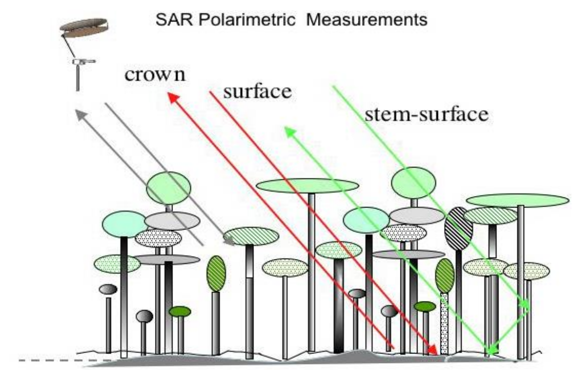
$$+\left(\rho_l \sigma_{pqldr2} + \rho_b\sigma_{pqb1dr2} + \rho_{b2}\sigma_{pqb2dr2}\right) r_g \left|\Gamma_q\right|^2\left[\frac{1-\exp\left(-2\,\mathrm{Im}\{K_{pc}-K_{qc}\}d_c\right)}{2\,\mathrm{Im}\{K_{pc}-K_{qc}\}}\right]$$

$$+2\,\mathrm{Re}\left\{\left(\rho_l \sigma_{pqldr12} + \rho_b\sigma_{pqb1dr12} + \rho_{b2}\sigma_{pqb2dr12}\right) r_g \left(\Gamma_q\Gamma_q^*\right)\left[\frac{1-\exp\left(-2i\,\mathrm{Re}\{K_{pc}-K_{qc}\}d_c\right)}{2i\,\mathrm{Re}\{K_{pc}-K_{qc}\}}\right]\right\}$$

$$\sigma^o_{pq\_trunk-ground} = \left(\rho_t \sigma_{pqtdr1}\right) r_g \left|R_p\right|^2\left[\frac{1-\exp\left(-2\,\mathrm{Im}\{K_{qt}-K_{pt}\}d_t\right)}{2\,\mathrm{Im}\{K_{qt}-K_{pt}\}}\right]\beta_t$$

$$+\left(\rho_t \sigma_{pqtdr2}\right) r_g \left|R_q\right|^2\left[\frac{1-\exp\left(-2\,\mathrm{Im}\{K_{pt}-K_{qt}\}d_t\right)}{2\,\mathrm{Im}\{K_{pt}-K_{qt}\}}\right]\beta_t$$

$$+2\,\mathrm{Re}\left\{\left(\rho_t \sigma_{pqtdr12}\right) r_g \left(R_q R_q^*\right)\left[\frac{1-\exp\left(-2i\,\mathrm{Re}\{K_{pt}-K_{qt}\}d_t\right)}{2i\,\mathrm{Re}\{K_{pt}-K_{qt}\}}\right]\right\}$$



$$r_g = \exp\left(-4k_o^2 s^2\cos^2\theta\right)$$

$$\Gamma_p = R_p\exp\left(2i\left[K_{pc}d_c + K_{pt}d_t\right]\right)$$

$$\sigma_{pq\alpha d} = 4\pi\left\langle\left|f_{pq\alpha d}\right|^2\right\rangle,\ \sigma_{pq\alpha dr1} = 4\pi\left\langle\left|f_{pq\alpha dr1}\right|^2\right\rangle,\ \sigma_{pq\alpha dr2} = 4\pi\left\langle\left|f_{pq\alpha dr2}\right|^2\right\rangle,$$

$$\sigma_{pq\alpha dr12} = 4\pi\left\langle f_{pq\alpha dr1} f^*_{pq\alpha dr1}\right\rangle$$

$$K_{qc} = k_o\cos\theta + \frac{2\pi}{k_o\cos\theta}\left[\rho_l\left\langle f^f_{qql}\right\rangle + \rho_{b1}\left\langle f^f_{qqb1}\right\rangle + \rho_{b2}\left\langle f^f_{qqb2}\right\rangle\right]$$

$$K_{qt} = k_o\cos\theta + \frac{2\pi}{k_o\cos\theta}\left[\rho_t\left\langle f^f_{qqt}\right\rangle\right]$$

Forward model expression

Simplification of the distorted Born approximation

Born approximation model requires detailed information about vegetation structure

$$\sigma^0_{HH} = A_{HH}\cos\theta_0 W^{\alpha_{HH}}(1-\exp(-B_{HH}W^{\beta_{HH}}\sec\theta_0)) + C_{HH}\Gamma_{HH}W^{\delta_{HH}}\sin(\theta_0)\exp(-B_{HH}W^{\beta_{HH}}\sec\theta_0) + S_{HH}\exp(-B_{HH}W^{\beta_{HH}}\sec\theta_0)$$

$$\sigma^0_{VV} = A_{VV}\cos\theta_0 W^{\alpha_{VV}}(1-\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0)) + C_{VV}\Gamma_{VV}W^{\delta_{VV}}\sin(\theta_0)\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0) + S_{VV}\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0)$$

$$\sigma^0_{HV} = A_{HV}\cos\theta_0 W^{\alpha_{HV}}(1-\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)) + C_{HV}\Gamma_{HV}W^{\delta_{HV}}\sin(\theta_0)\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0) + S_{HV}\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)$$

W is the biomass (Mg/ha)

$$\Gamma_{pq} = R_p R_q^* \exp\left(-4k^2 s^2 \cos^2(\theta_0)\right)$$

s is the rms height

k is the wavenumber

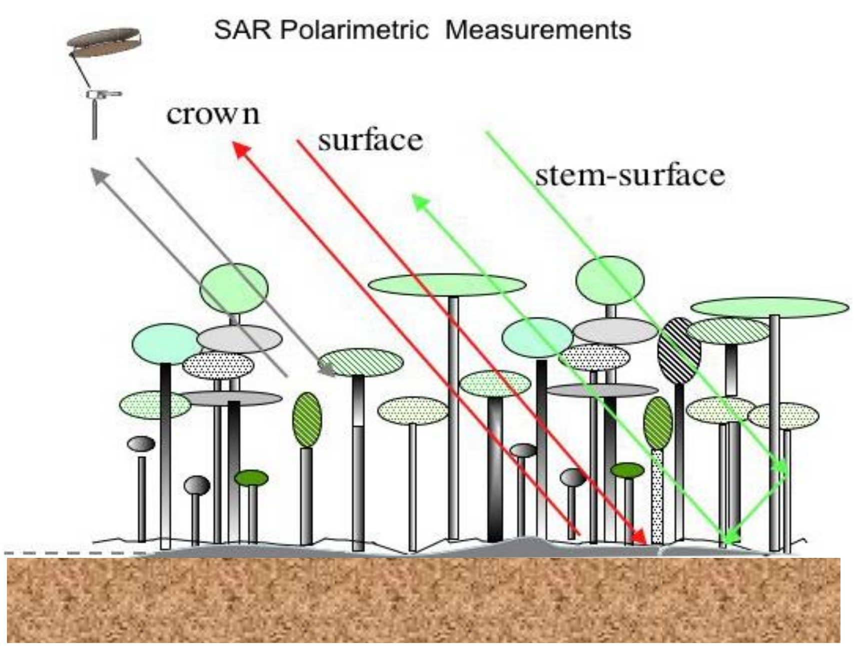
R_p and R_q arethe Fresnel reflection coefficients

S_{HH}, S_{VV} and S_{HV} are the scattering term from bare soil su

θ_0 is the local incidence angle

α_{pq}, β_{pq}, δ_{pq} are structural parameters

A_{pq}, B_{pq} and C_{pq} are calibration factors



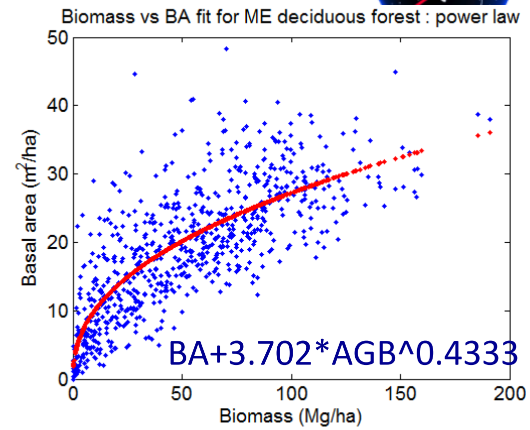
Deriving structure parameters

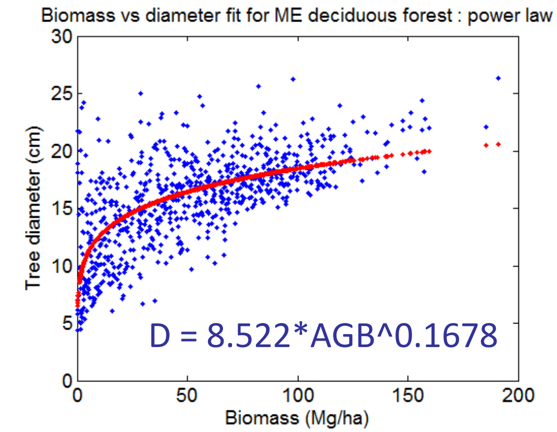
- Forest Inventory Agency (FIA) data provides
  - Tree species
  - Tree height
  - Tree diameter
  - Density of tree and more
- We find fits for these information as a function of above ground biomass (AGB)
- Using the information for fits, we simulate backscatter and its component (direct, direct reflect, and the exponential decay factor) using distort Born model
- We capture information on average for each forest in ‘structure parameters’ α_{pq}, β_{pq}, δ_{pq} as a function of biomass

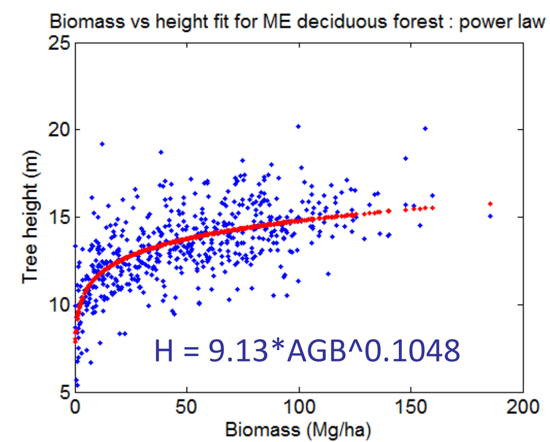
Deriving structure parameters

- Trunk parameter
  - Use data for these relationship:
    - AGB with Basal Area (BA)
    - AGB with total tree Height (H)
    - AGB with average Diameter (D)
  - Tree Per Hectare (TPH) = 4BA/(pi*D^2)
  - Use Jenkin's eq. to get Biomass of Trunk (Bt)
  - Height of Trunk (Ht) = 4BT/(gt*TPH*piD^2)

    where gt is the specific gravity of trunk
  - Crown height = H – Ht
- Branch parameter
  - Use Jenkin's eq to get Biomass of branch -> Bb
  - Interpolate branch length using relationship of AGB and trunk height * a factor (0.2)
  - Interpolate branch diameter using relationship of AGB and trunk diameter * a factor (0.2)
  - Branch density (BPH) = 4*Bb/(gb*pi*Db^2*Lb) where gb is the specific gravity of branch

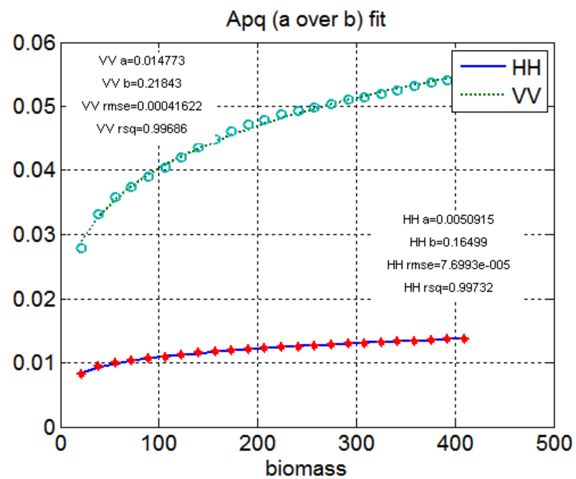


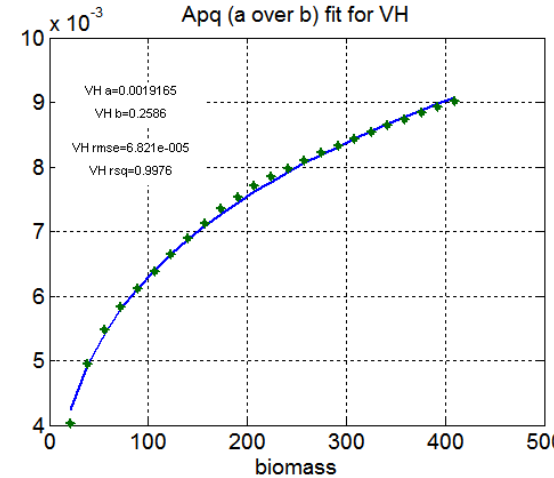


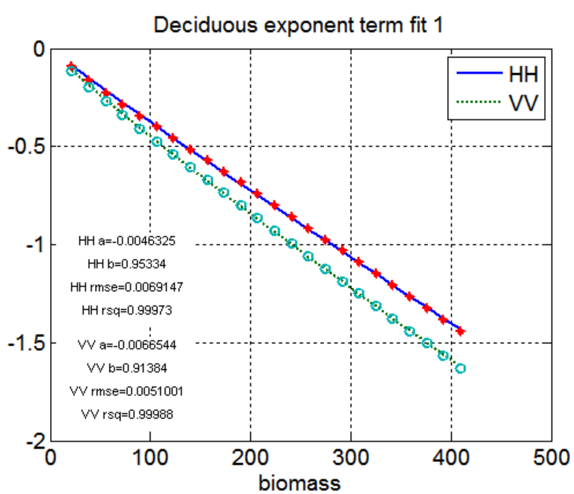


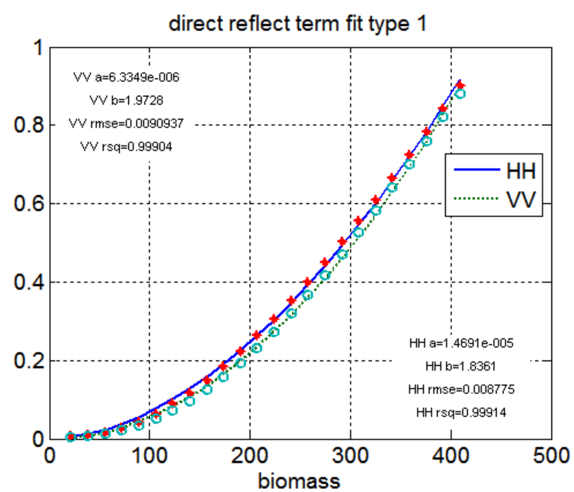
Structure parameter fit

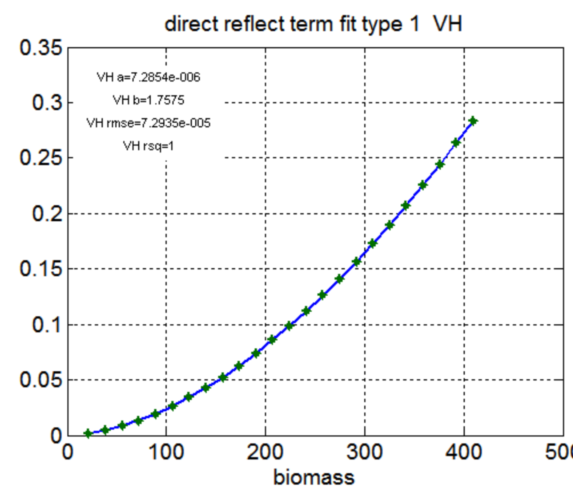
	a_{pq}	b_{pq}	d_{pq}
HH	0.16499	0.95334	1.8361
VV	0.21843	0.91384	1.9728
HV	0.2568		1.7575











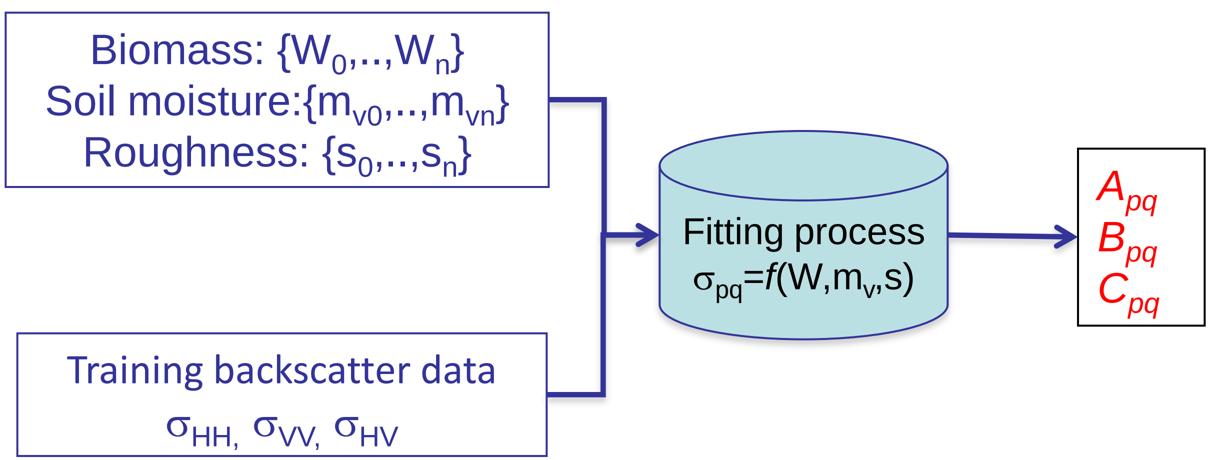
Training the model to site data

$$\sigma^0_{HH} = A_{HH}\cos\theta_0 W^{\alpha_{HH}}(1-\exp(-B_{HH}W^{\beta_{HH}}\sec\theta_0)) + C_{HH}\Gamma_{HH}W^{\delta_{HH}}\sin(\theta_0)\exp(-B_{HH}W^{\beta_{HH}}\sec\theta_0) + S_{HH}\exp(-B_{HH}W^{\beta_{HH}}\sec\theta_0)$$

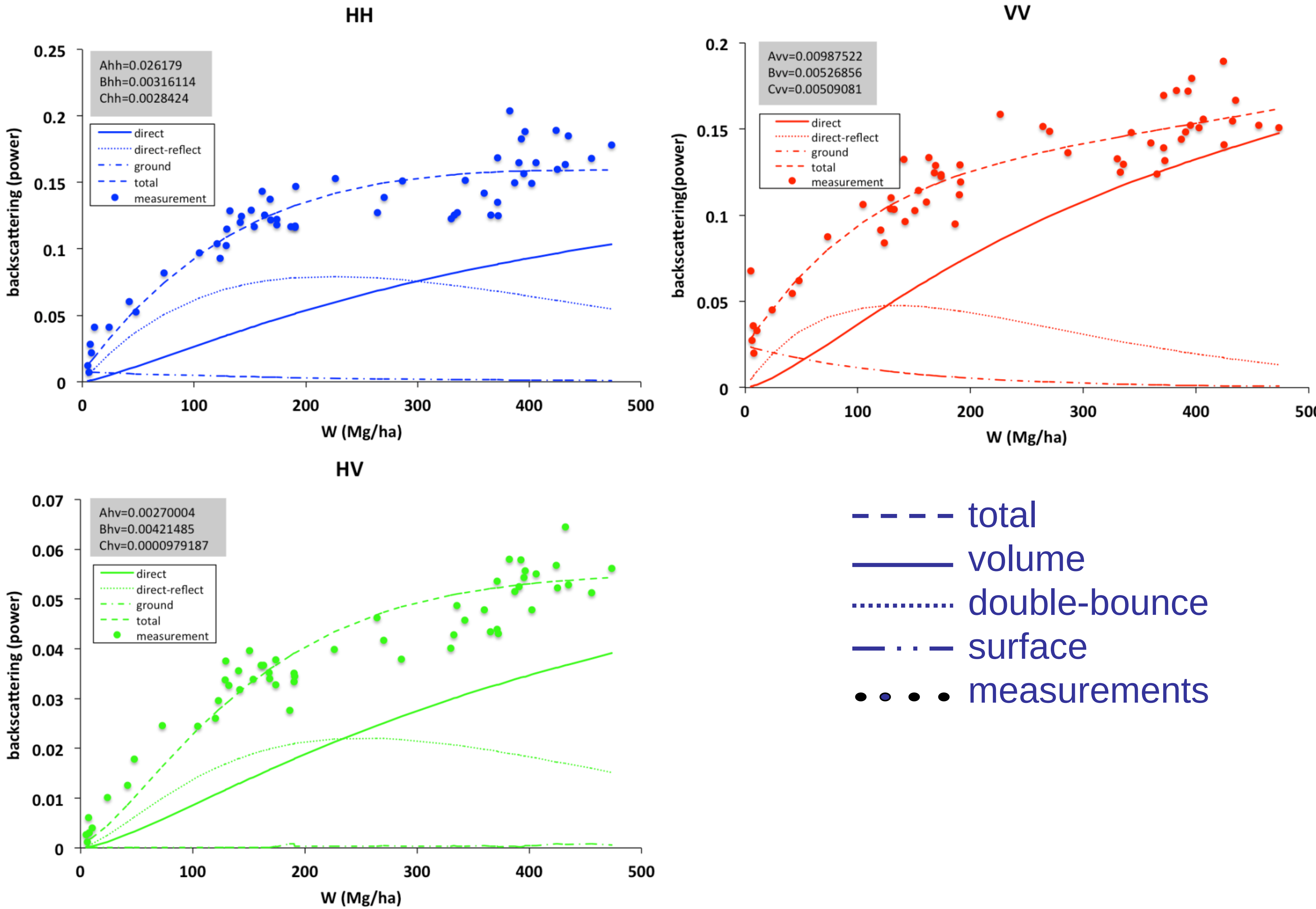
$$\sigma^0_{VV} = A_{VV}\cos\theta_0 W^{\alpha_{VV}}(1-\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0)) + C_{VV}\Gamma_{VV}W^{\delta_{VV}}\sin(\theta_0)\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0) + S_{VV}\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0)$$

$$\sigma^0_{HV} = A_{HV}\cos\theta_0 W^{\alpha_{HV}}(1-\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)) + C_{HV}\Gamma_{HV}W^{\delta_{HV}}\sin(\theta_0)\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0) + S_{HV}\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)$$

- Calibrated SAR data
- Use average soil moisture and roughness for the site
- Use plot level biomass values
- Create a series of points to estimate coefficients A_{pq}, B_{pq}, C_{pq}

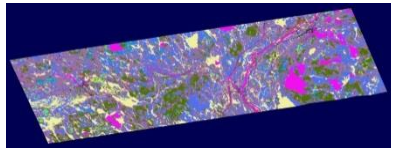


Backscatter model vs data

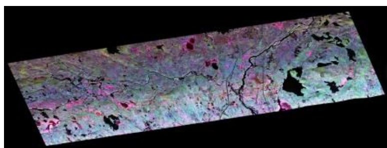


Inversion process

NLCD



{R;G;B}={σ_{VV};σ_{HV};σ_{HH}}



classification

$$s_0 = \begin{cases} s & \text{surface} \\ mean(s) & \text{vegetated areas} \end{cases}$$

$$m_{v_0} = \begin{cases} m_v & \text{surface} \\ mean(m_v) & \text{vegetated areas} \end{cases}$$

$$\sqrt{W} = a_0 + a_1\sigma_{HH} + a_2\sigma_{HV} + a_3\sigma_{VV} \quad (1)$$

Initial data & bounds

- W_0, M_{v0} (ε_0), s_0
- 0 < ε' < 80
- 0 < W' < 300
- 0 < s' < 0.1

Inversion process

Levenberg-Marquardt algorithm:

$$S(W,\varepsilon,s) = \sum_{i=1}^{n}\left[\sigma_{pq} - f(W,\varepsilon,s)\right]^2$$

W'

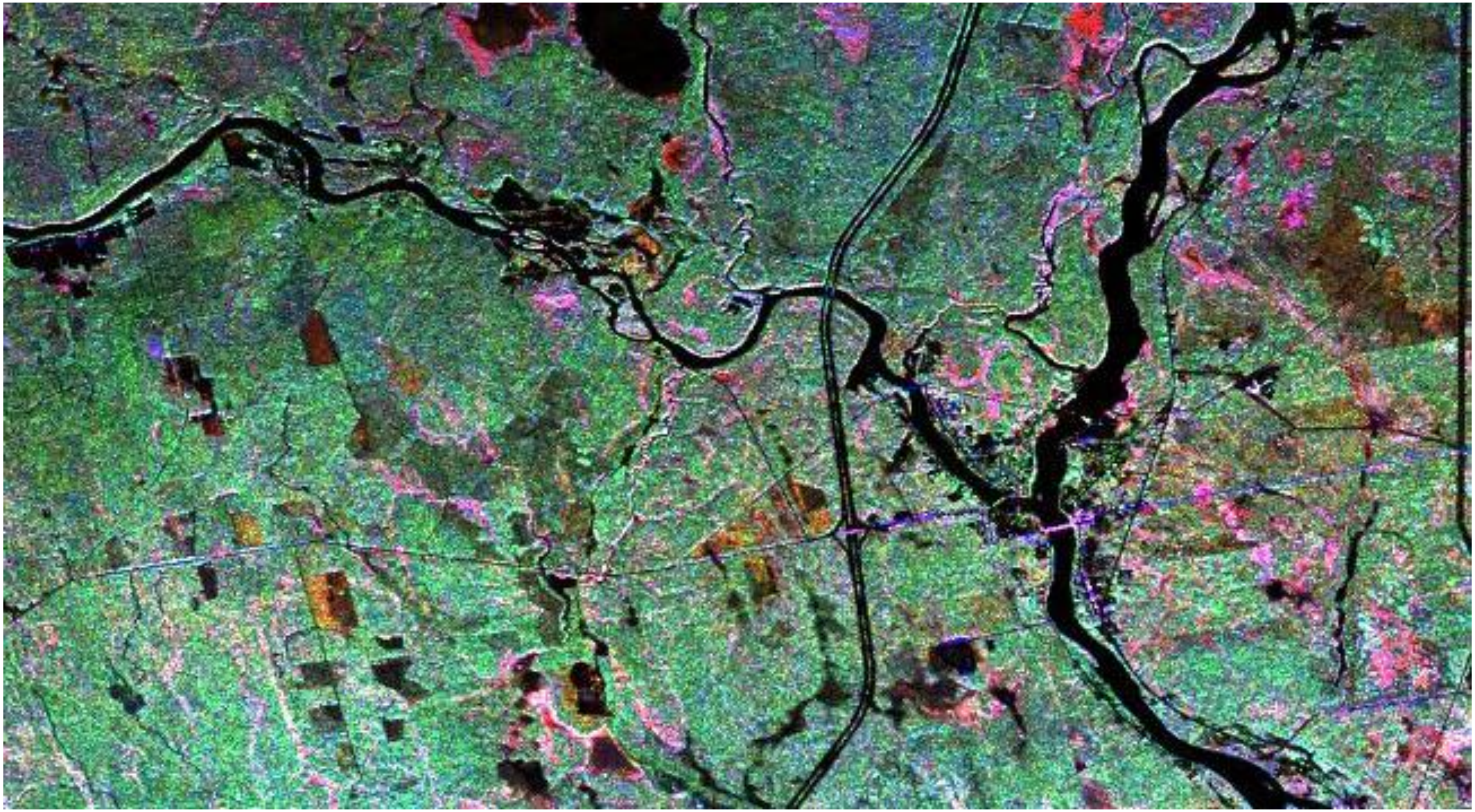
ε'

s'

(1) *"Impact of spatial variability of tropical forest structure on radar estimation of aboveground biomass", S. Saatchi, M. Marlier, R. L. Chazdon, D. B. Clark, A. E. Russell, Remote Sensing of Environment, vol. 115, no. 11, pp. 2836-2849, 2011.*

Application

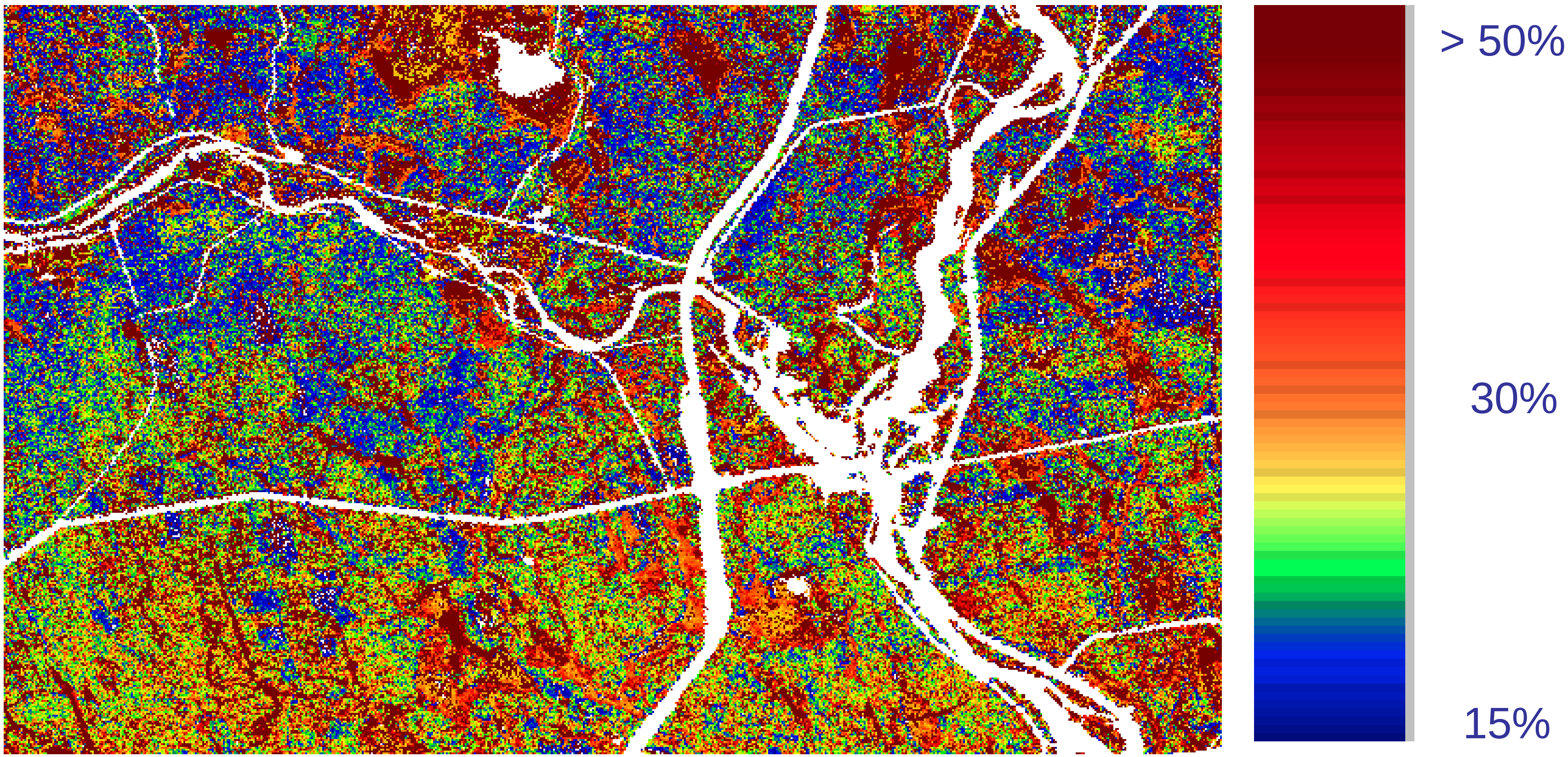
AirSAR data - Howland forest – Maine – October 1994



σ_{VV} ; σ_{HV} ; σ_{HH}

Pixel Size: 1 arcsec

Soil moisture map



0 < mv < 50%
Ground measurement = 18.4%
Estimated value on this particular point = 21.5%

Field campaign

Howland forest – October 2012

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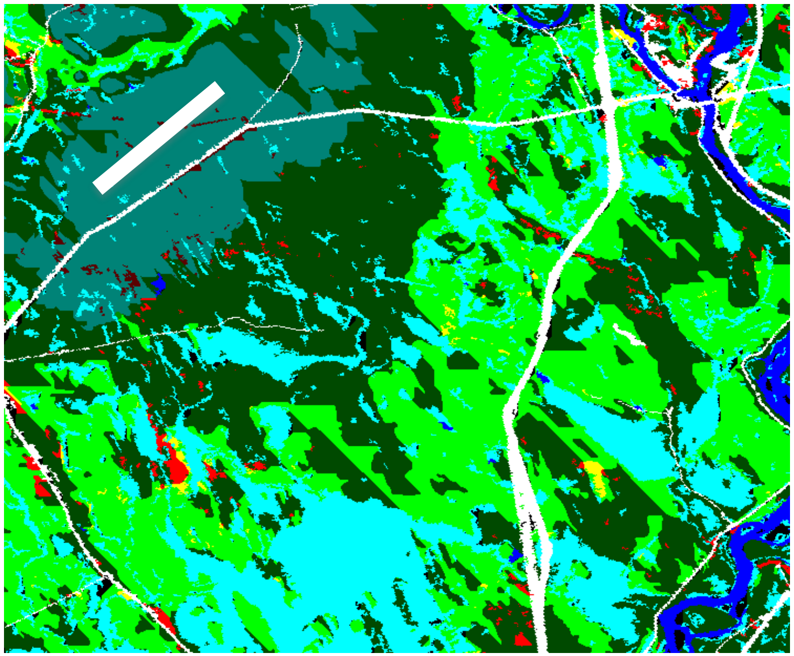
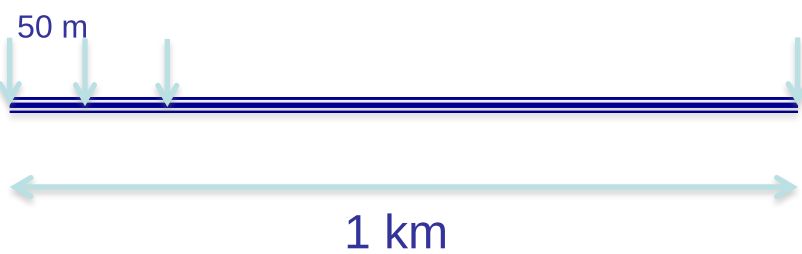
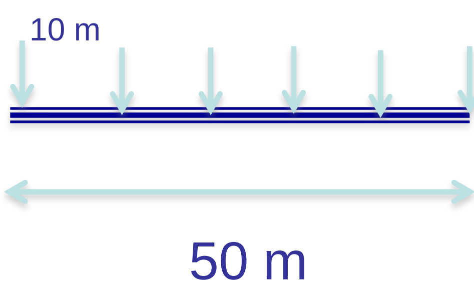
Soil Moisture TDR Sensors

Data sampling strategy



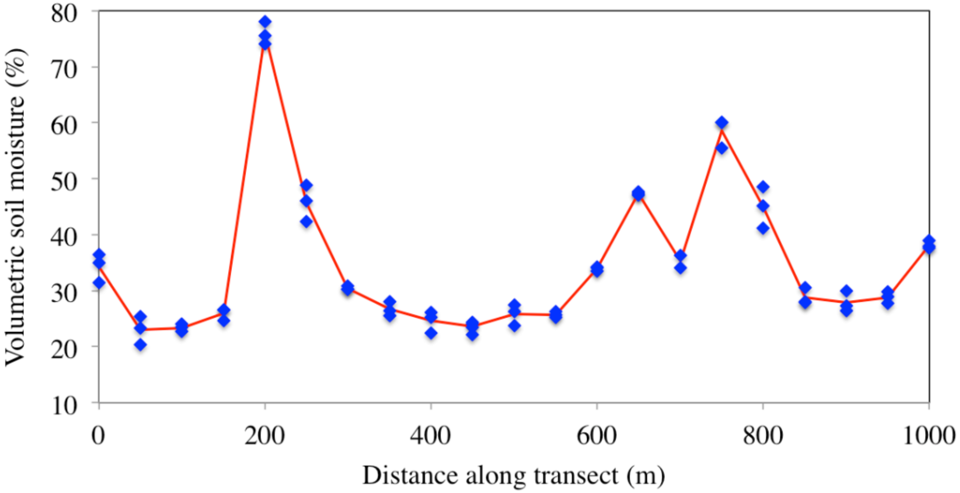
1 km transects with sampling at 50m intervals with GPS at each location

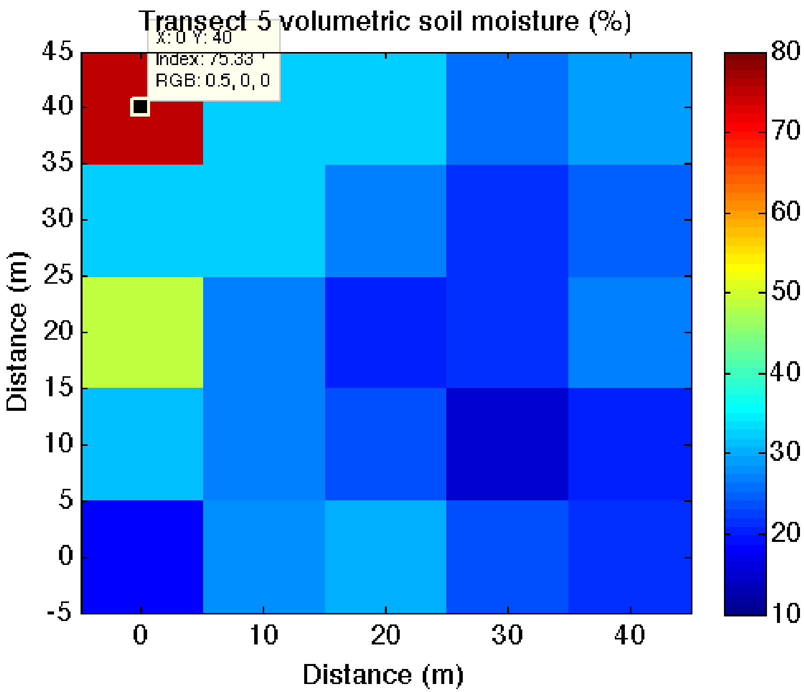


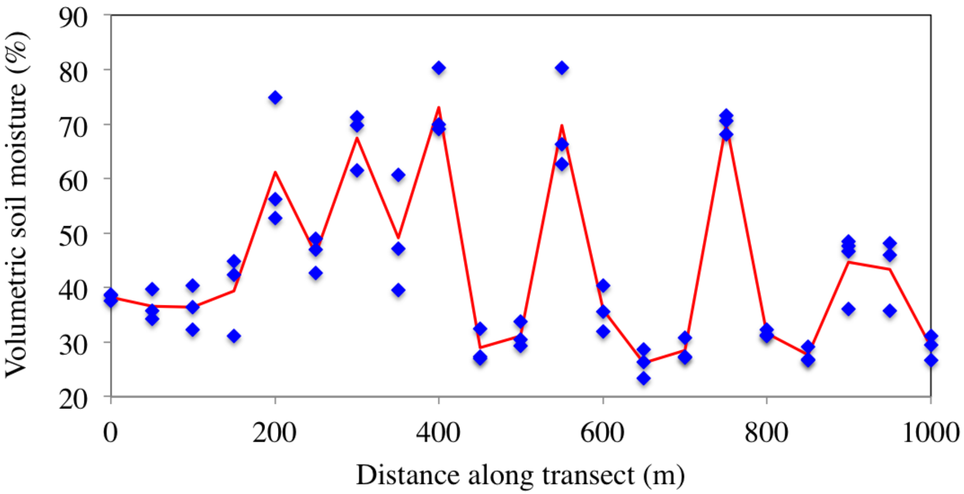


Collect 5 parallel 50 m transects
With sampling at 10m intervals
with GPS at each location

Field measurements examples







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Field Campaign – La Selva

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THANK YOU! QUESTIONS?