Soil moisture and biomass retrieval over forest areas using low frequency polarimetric SAR data

My-Linh Truong-Loï
Jet Propulsion Laboratory / California Institute of Technology

Postdoc seminar – December 11th 2012

© 2012 California Institute of Technology. Government sponsorship acknowledged.

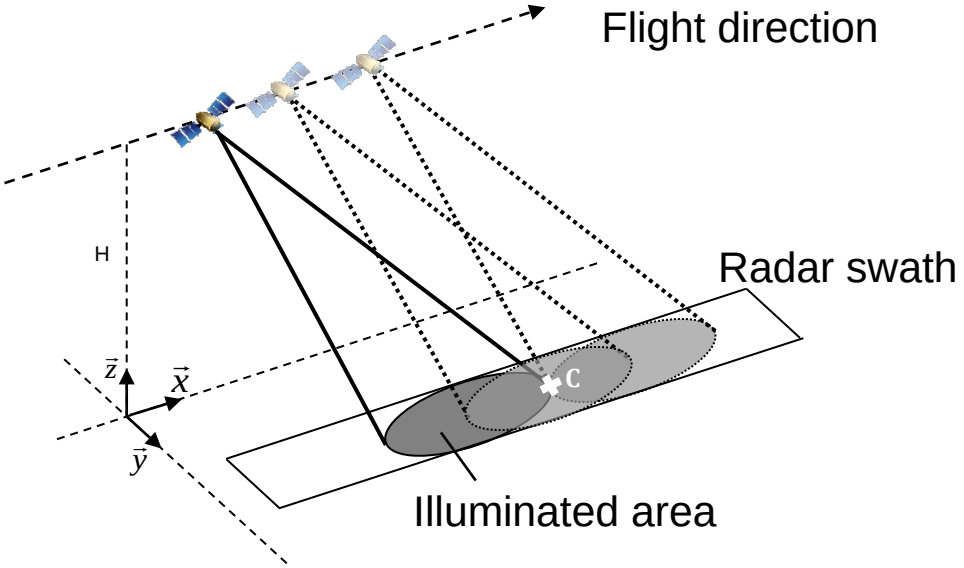
Outline

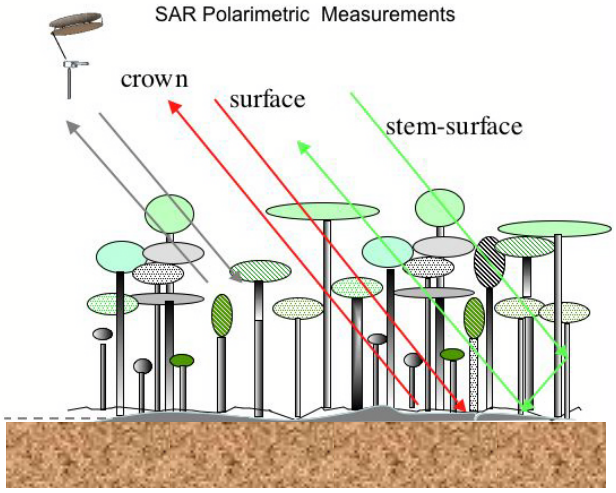
Objective: is it possible to estimate soil moisture under forest?

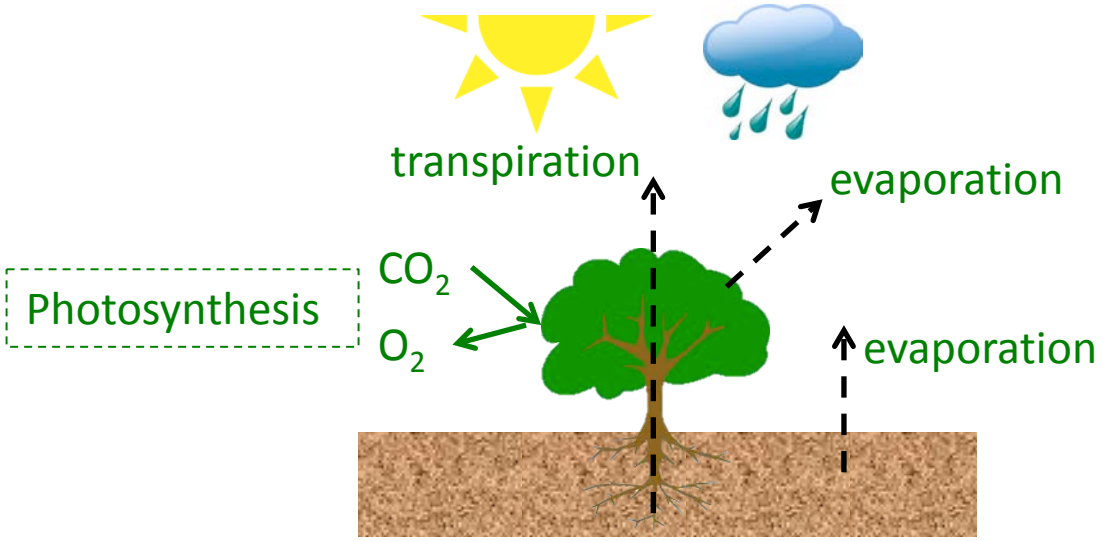
- Introduction
- Presentation of the model
- Inversion process
- Sensitivity analysis of the inversion process with simulated data
- Application with real data
- Explanation of field measurements

Context

- Synthetic aperture radar
- Low frequency
- Soil moisture



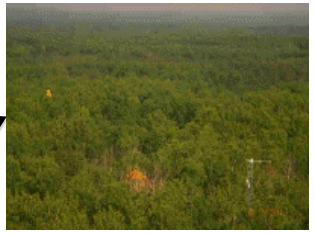




Context

Temperate evergreen forest

Boreal forest



Open shrubland

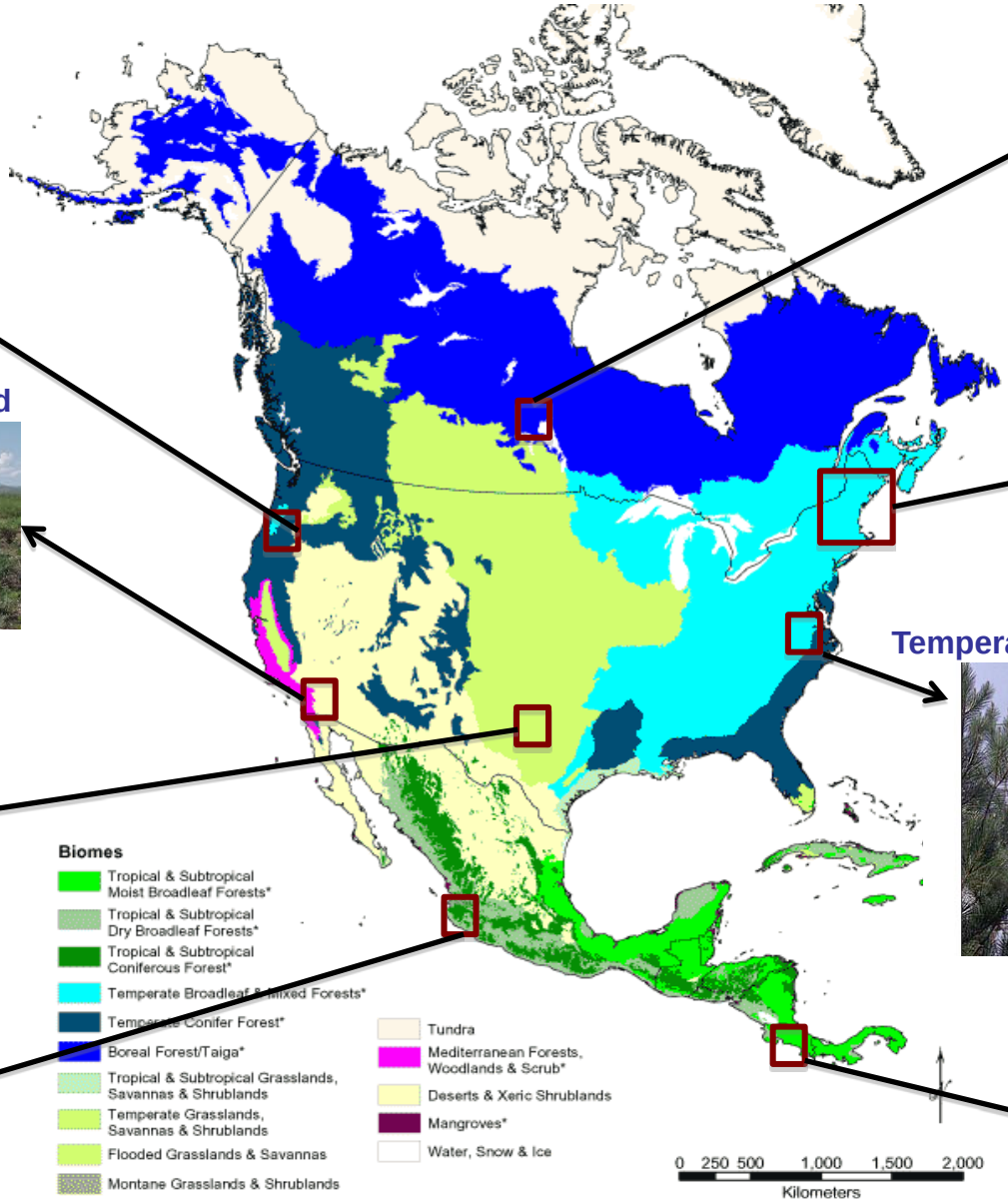
Boreal transitional

Temperate grasslands

Temperate mixed forest

Subtropical dry forest

Tropical moist forest



Forward model expression

➔Simplification of the distorted Born approximation

-complex

-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 being the Fresnel reflection coefficients of the ground for polarization p and q

S_{HH}, S_{VV} and S_{HV} being the scattering term from a rough surface model

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

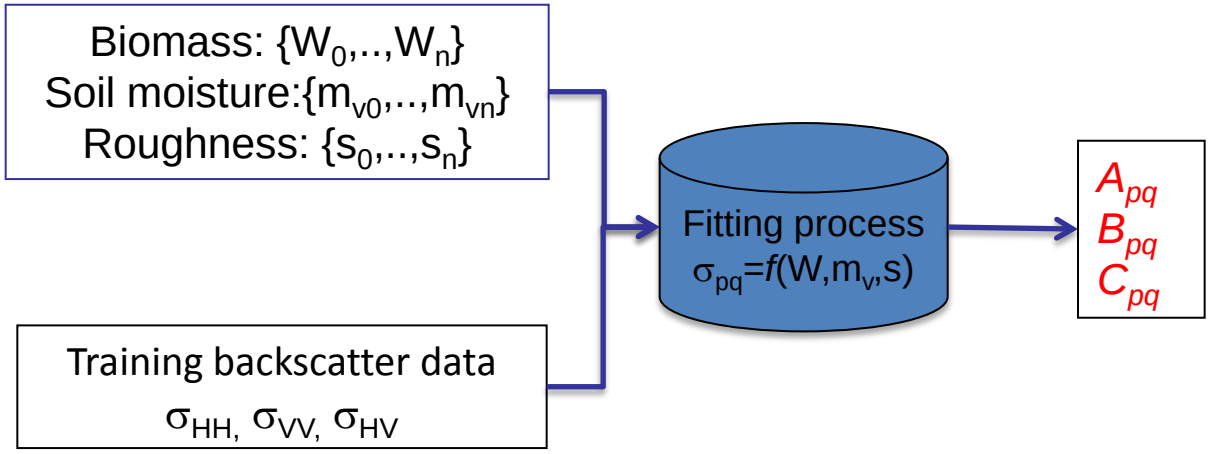
Training the model to site data

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

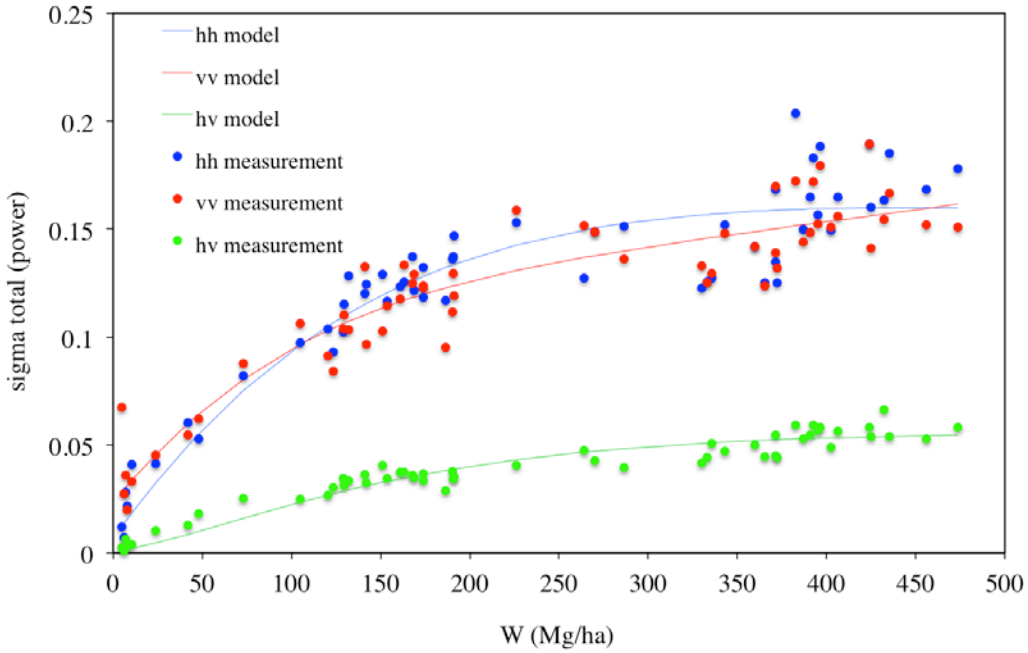
$$\sigma^0_{VV} = A_{VV}\cos\theta_0 W^{\alpha_{VV}}(1-\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0)) + C_{VV}\Gamma_{VV}W^{\delta_{VV}}\sin(\theta_0)\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0) + S_{VV}\exp(-B_{VV}W^{\beta_{VV}}\sec\theta_0)$$

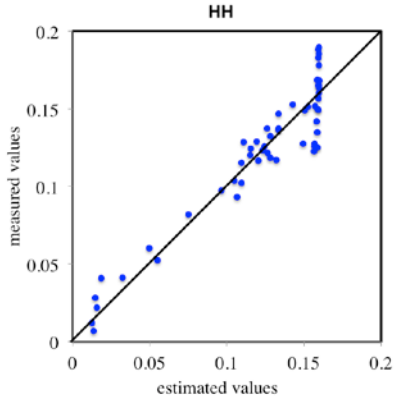
$$\sigma^0_{HV} = A_{HV}\cos\theta_0 W^{\alpha_{HV}}(1-\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)) + C_{HV}\Gamma_{HV}W^{\delta_{HV}}\sin(\theta_0)\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0) + S_{HV}\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)$$

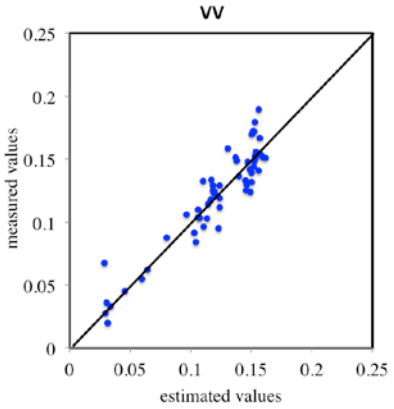
- Calibrated SAR data
- Use average soil moisture and roughness for the site
- Use plot level biomass values
- Create a series of points to estimate coefficients A_{pq}, B_{pq}, C_{pq}

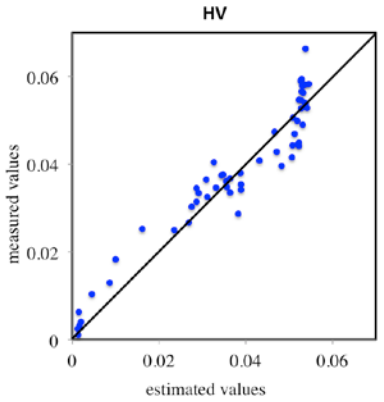


Model shape – tropical data



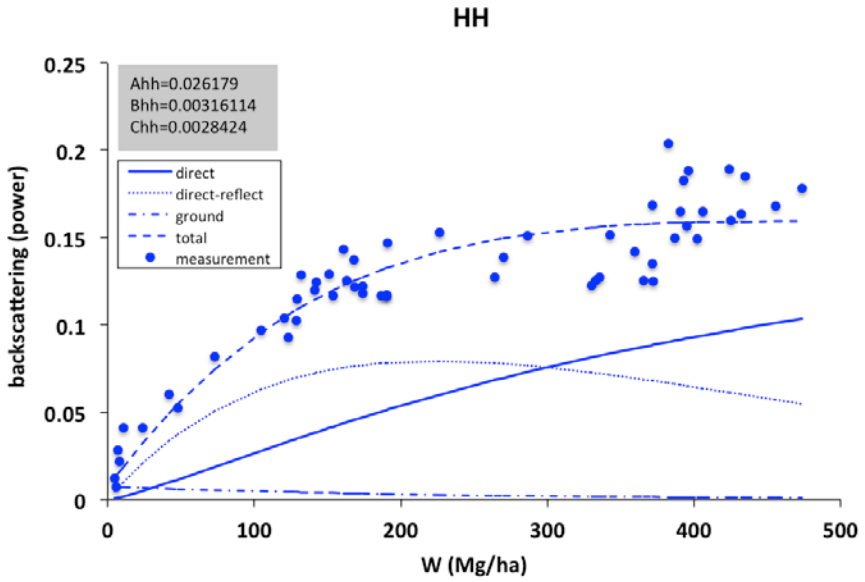


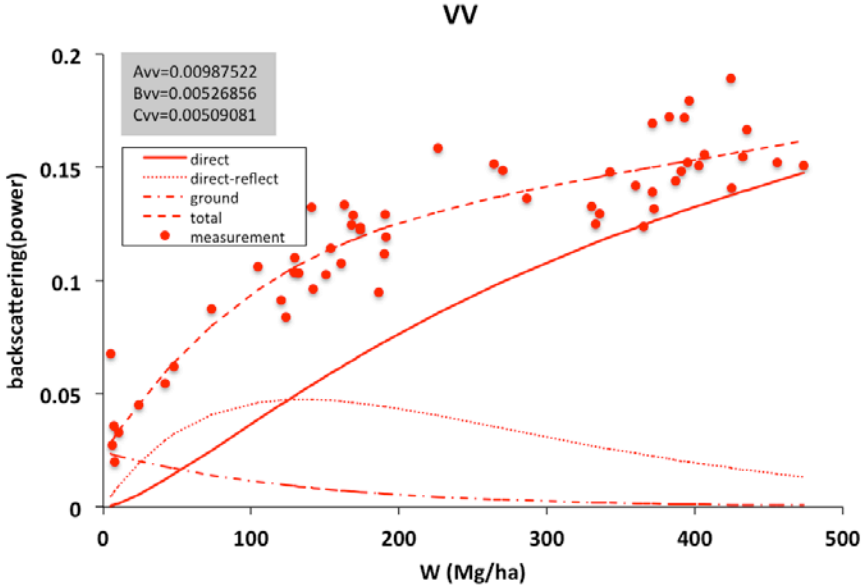


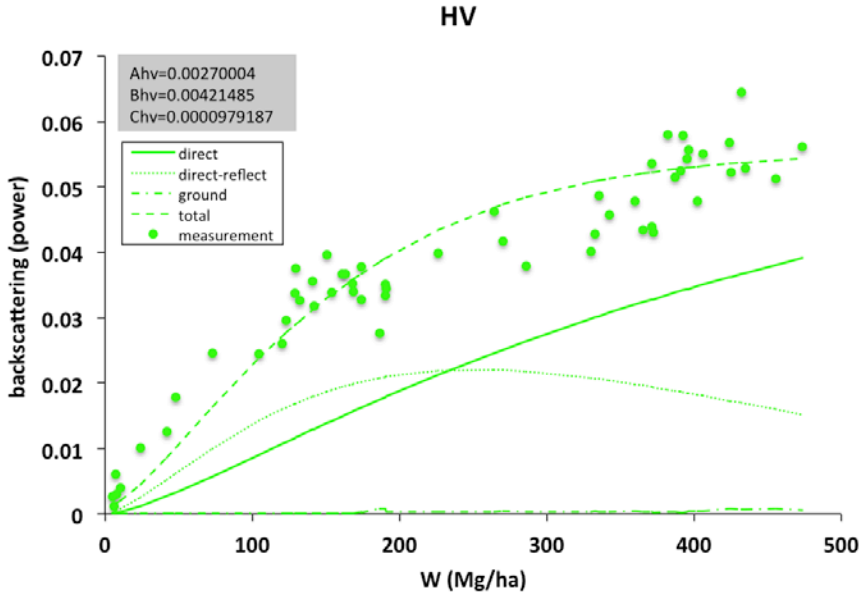


	HH	VV	HV
RMSE	0.016819935	0.0142891	0.00504441
R^2	0.930469068	0.933139812	0.955186855

Shape of each scattering







- - - - total

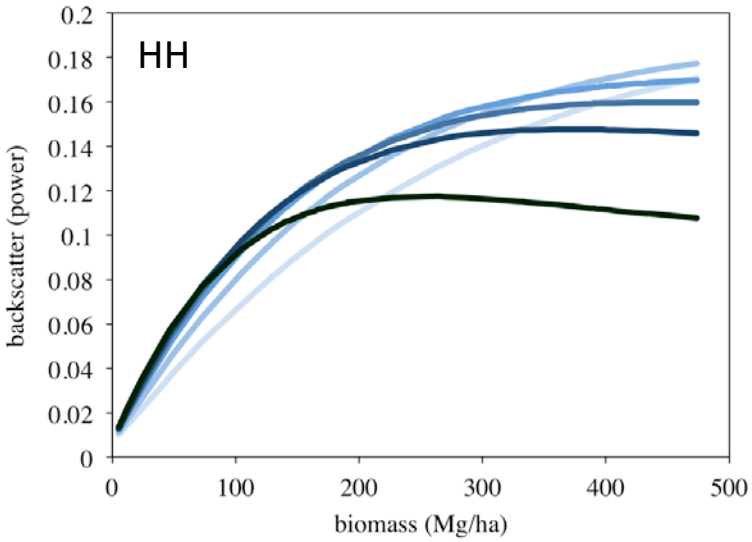
——— volume

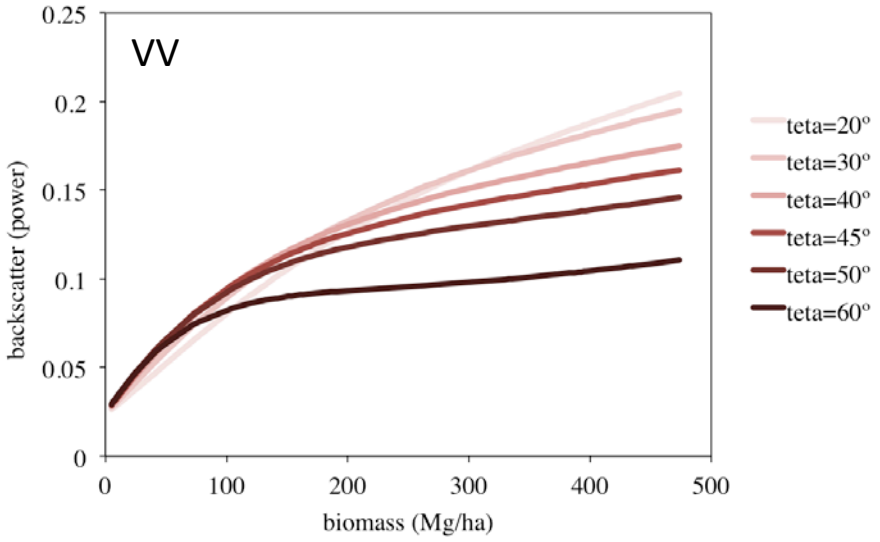
..... double-bounce

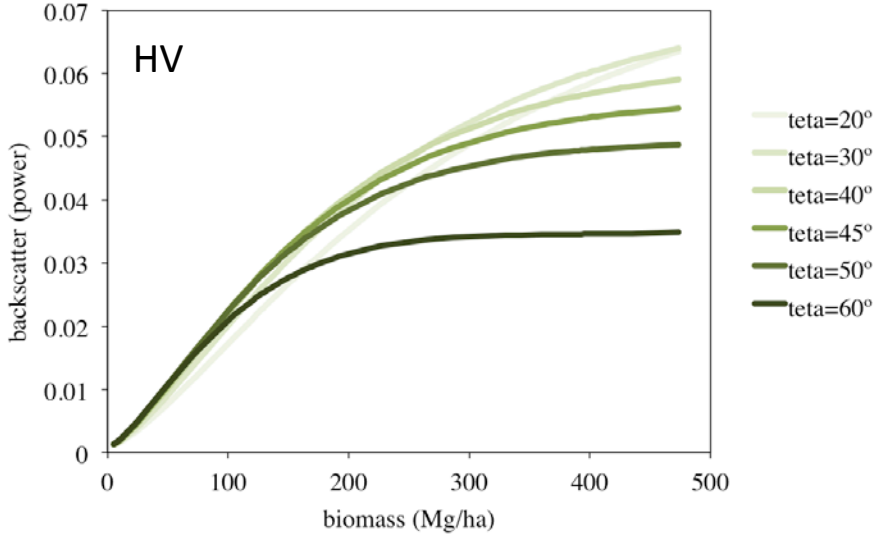
— · · — surface

• • • • measurements

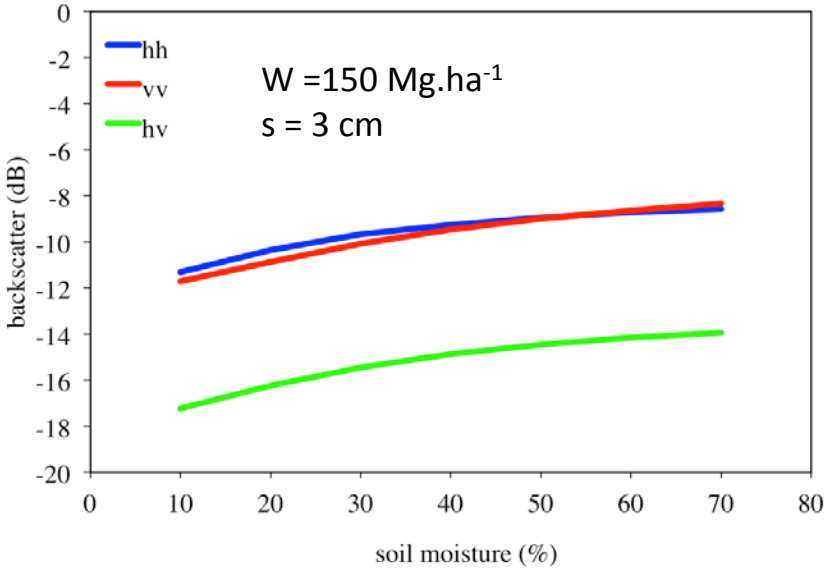
Incidence angle effect

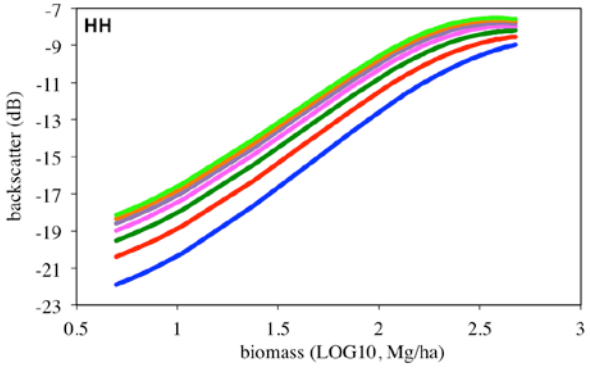


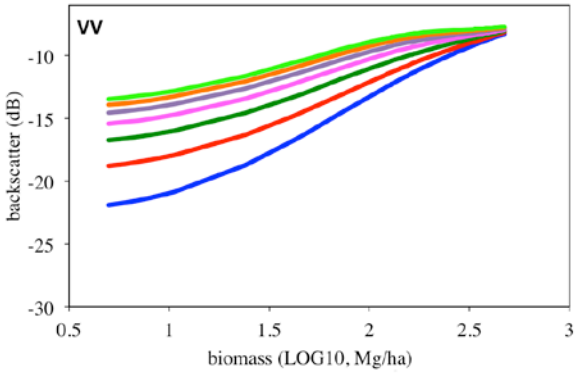


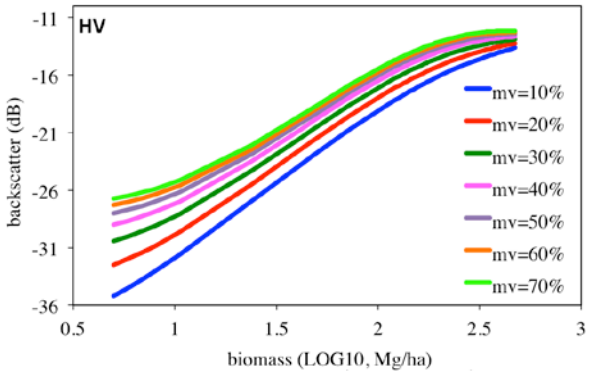


Soil moisture sensitivity



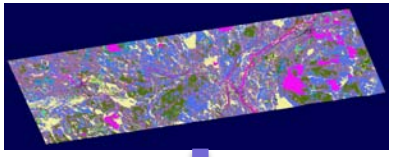




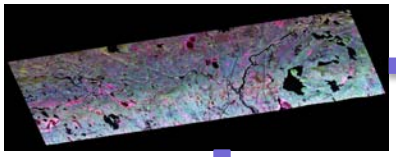


Inversion process

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:

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

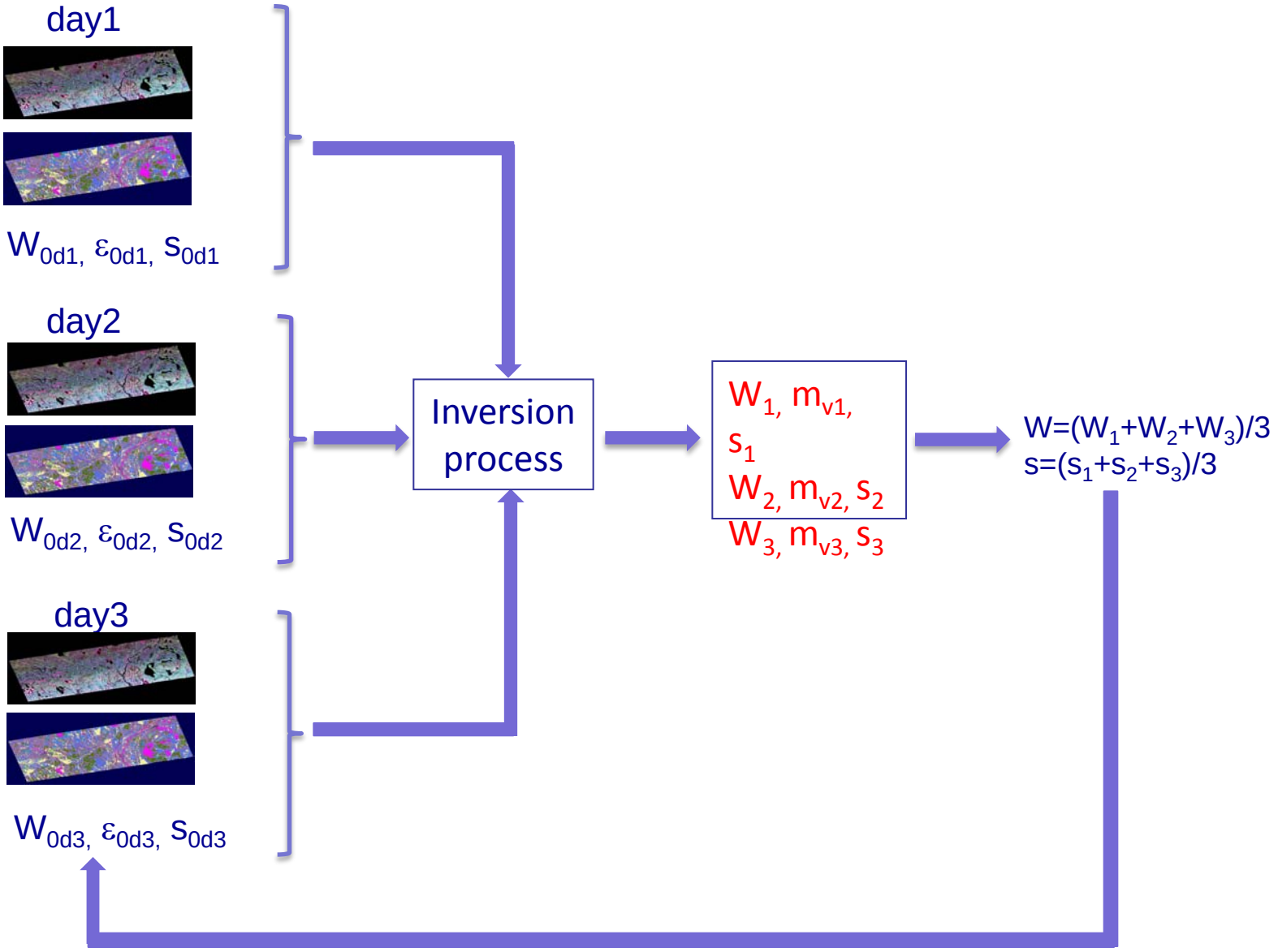
W'

ε

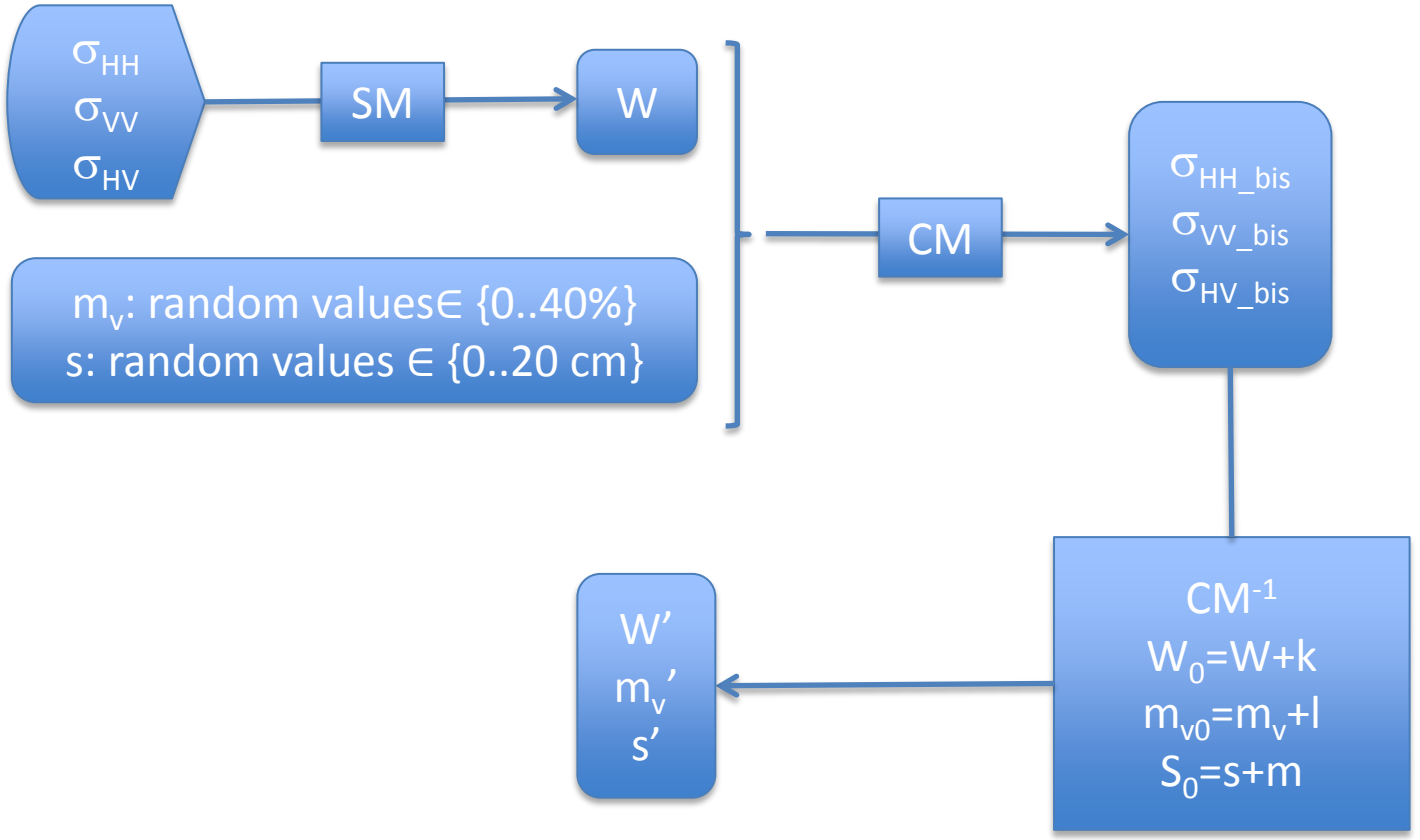
s'

(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.

With time series measurements



Sensitivity analysis



$k \in [-0.5 ; 0.5]*W$
$l \in [-0.5 ; 0.5]*m_v$
$m \in [-0.5 ; 0.5]*s$

SM: $\sqrt{W} = a_0 + a_1\sigma_{HH} + a_2\sigma_{HV} + a_3\sigma_{VV}$

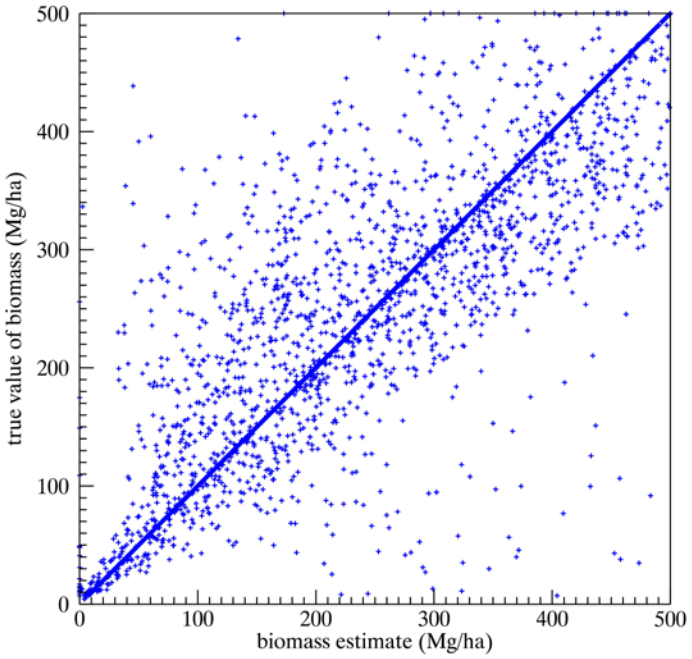
CM:

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

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

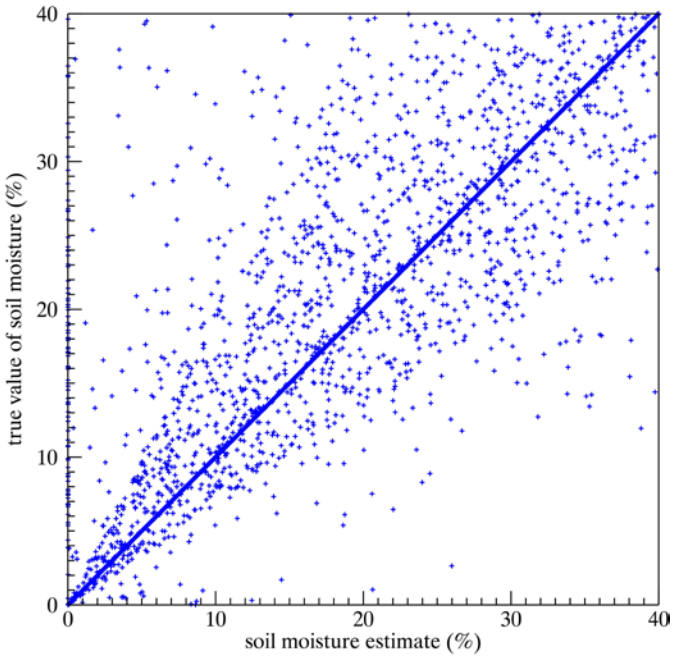
$$\sigma^0_{HV} = A_{HV}\cos\theta_0 W^{\alpha_{HV}}(1-\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)) + C_{HV}\Gamma_{HV}W^{\delta_{HV}}\sin(\theta_0)\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0) + S_{HV}\exp(-B_{HV}W^{\beta_{HV}}\sec\theta_0)$$

Sensitivity analysis - results



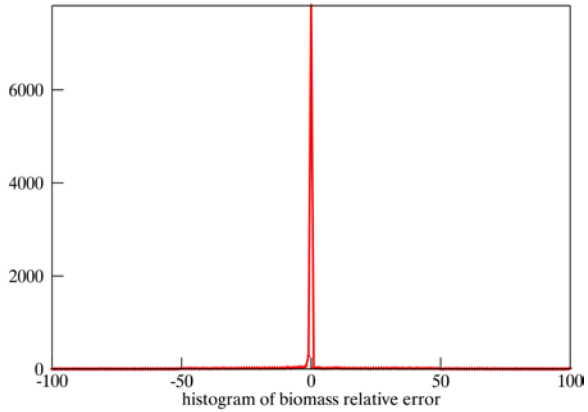
RMSE = 50 Mg/ha

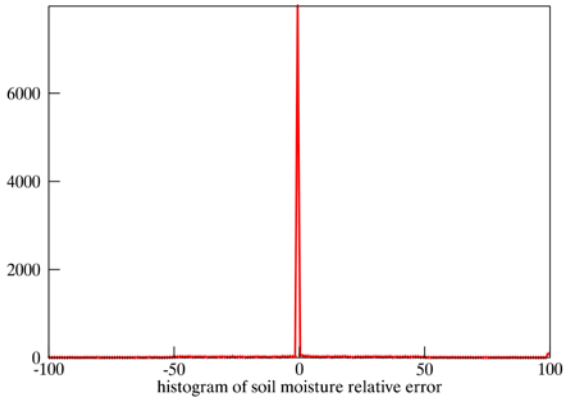
88% of pixels have a relative error ~ 0



RMSE = 4.35 %

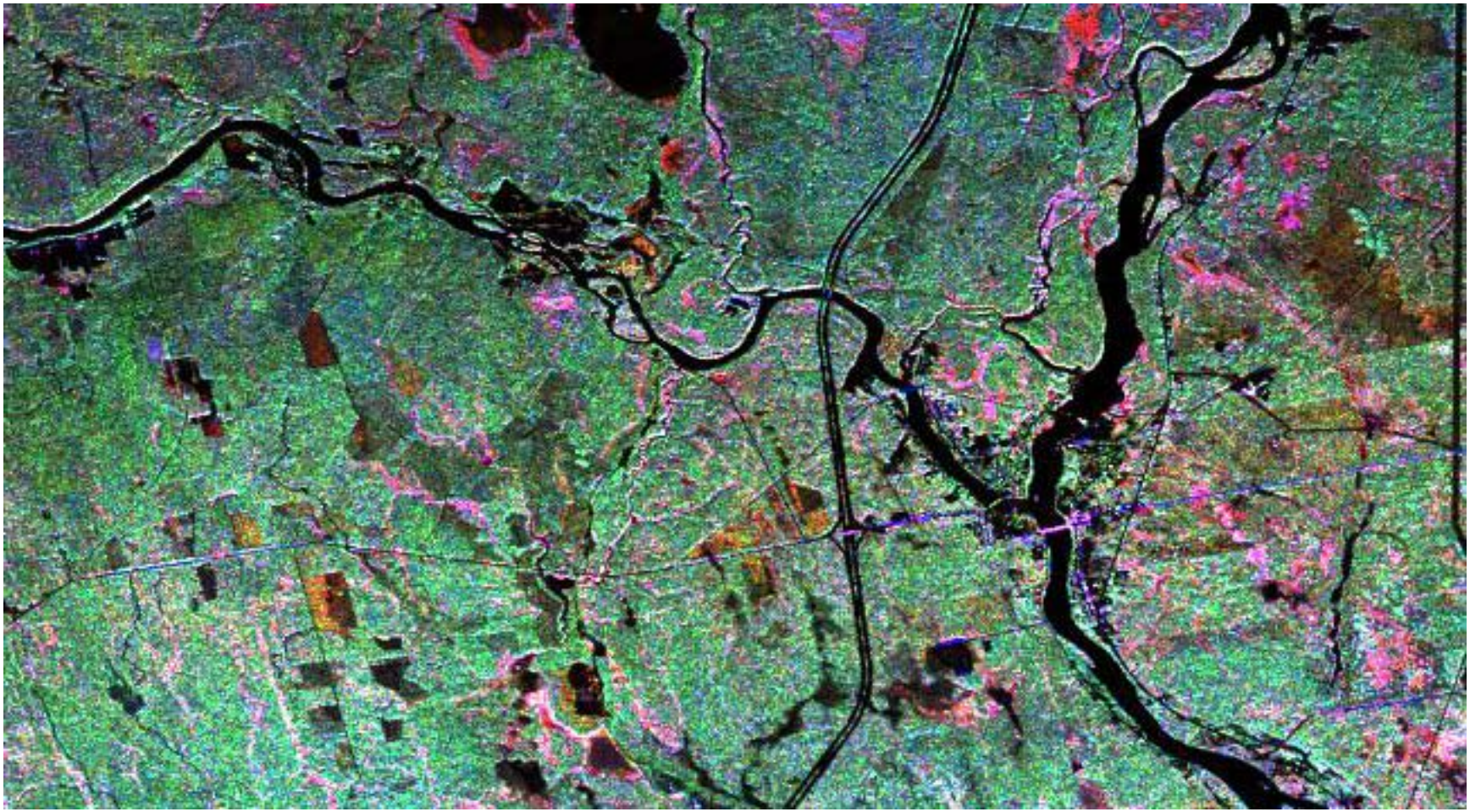
90% of pixels have a relative error ~ 0





Application

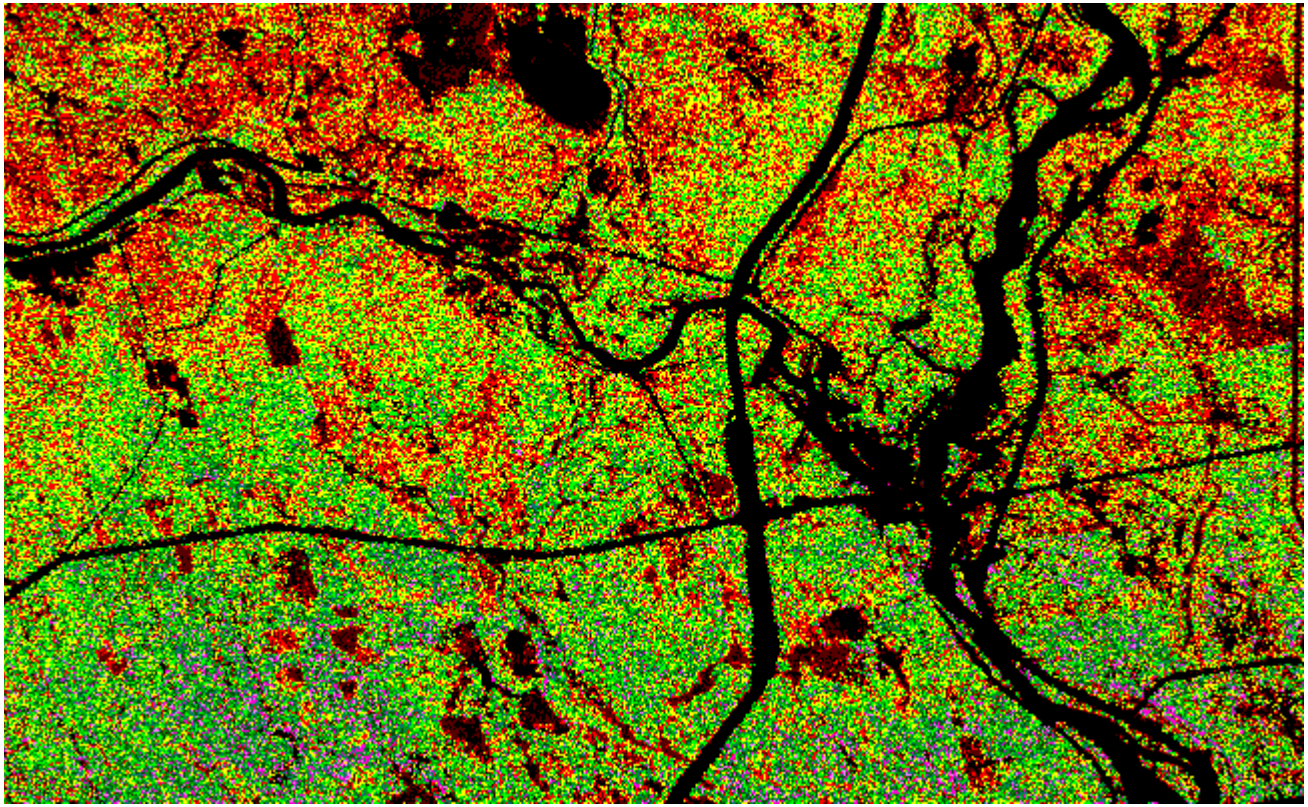
AirSAR data - Howland forest – Maine - October 1994



σ_{VV} ; σ_{HV} ; σ_{HH}

Pixel Size: 1 arcsec

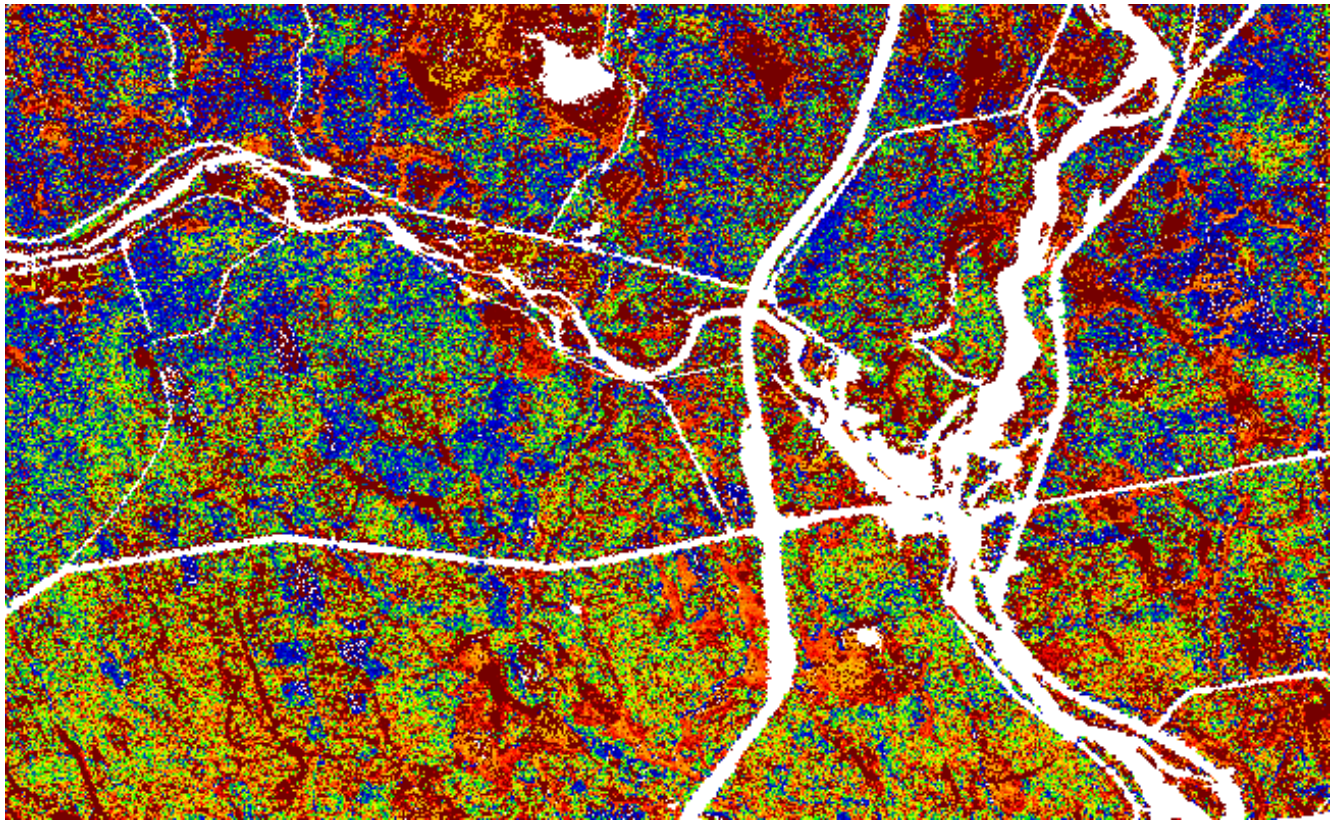
Aboveground Vegetation Biomass

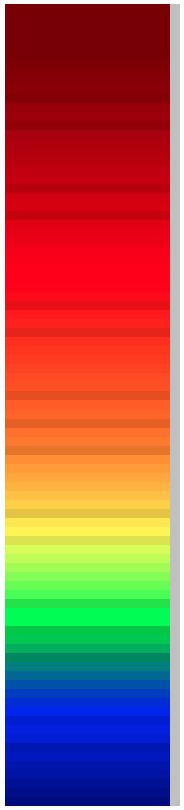


Non-Vegetated
< 25 Mg/ha
25 <AGB< 50
50 <AGB< 75
75 <AGB< 100
100 <AGB< 125
125 <AGB< 150
150 <AGB< 175
175 <AGB< 200
AGB>200

0 < W < 300 Mg/ha
Mean(W) = 64 Mg/ha

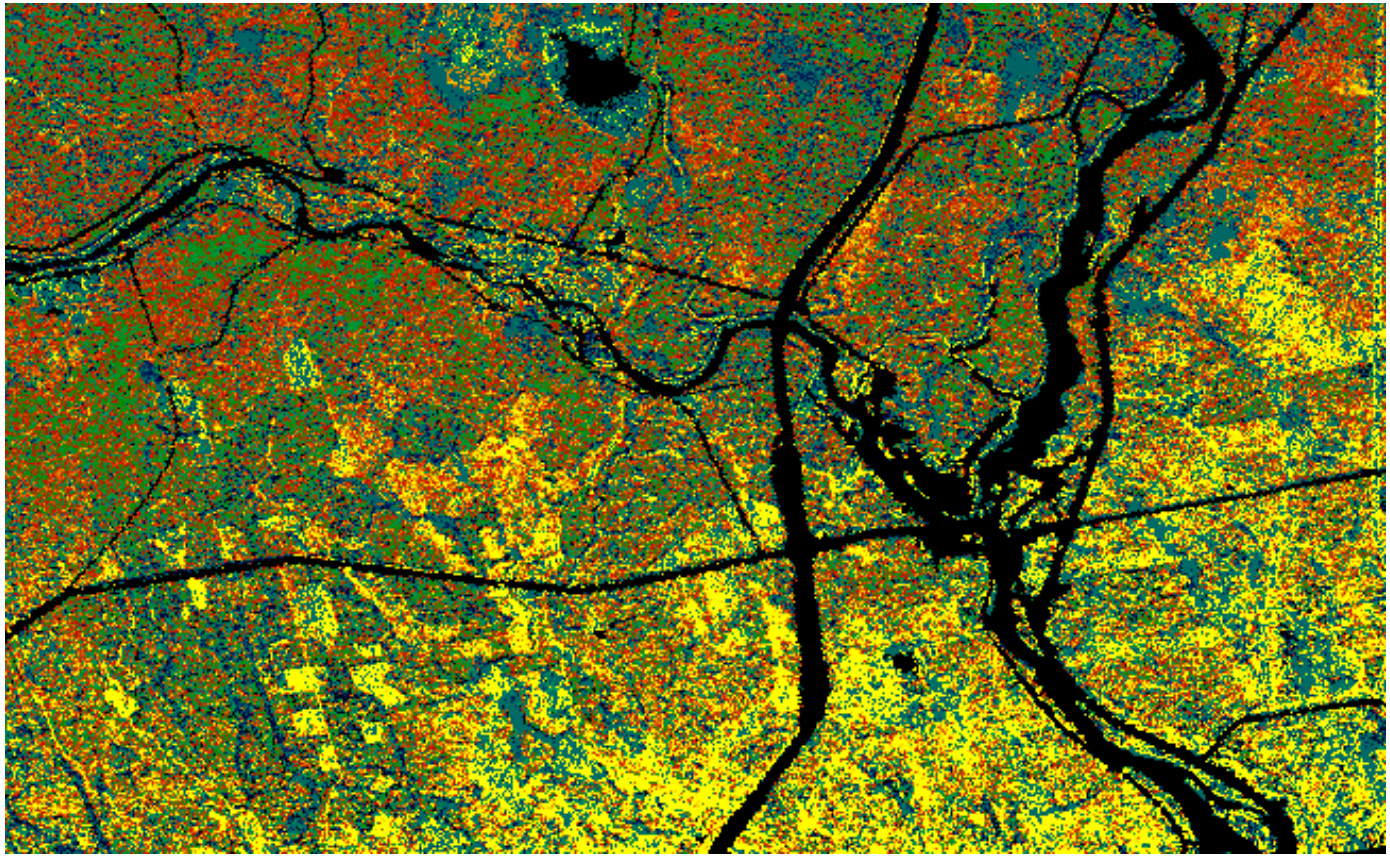
Soil moisture map





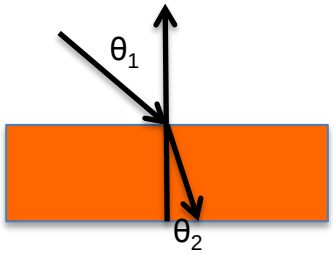
0 < mv < 50%
Ground measurement = 18.4%
Estimated value on this particular point = 21.5%

Soil penetration depth



$$d = \frac{-\log_e(0.1)\lambda}{2\pi n_i}; \quad n_i = \mathrm{Im}\left(\sqrt{\varepsilon_r}\right)$$

$$Depth = d\cos\theta_2, \quad \sin\theta_2\sqrt{\varepsilon_2} = \sin\theta_1\sqrt{\varepsilon_1}$$

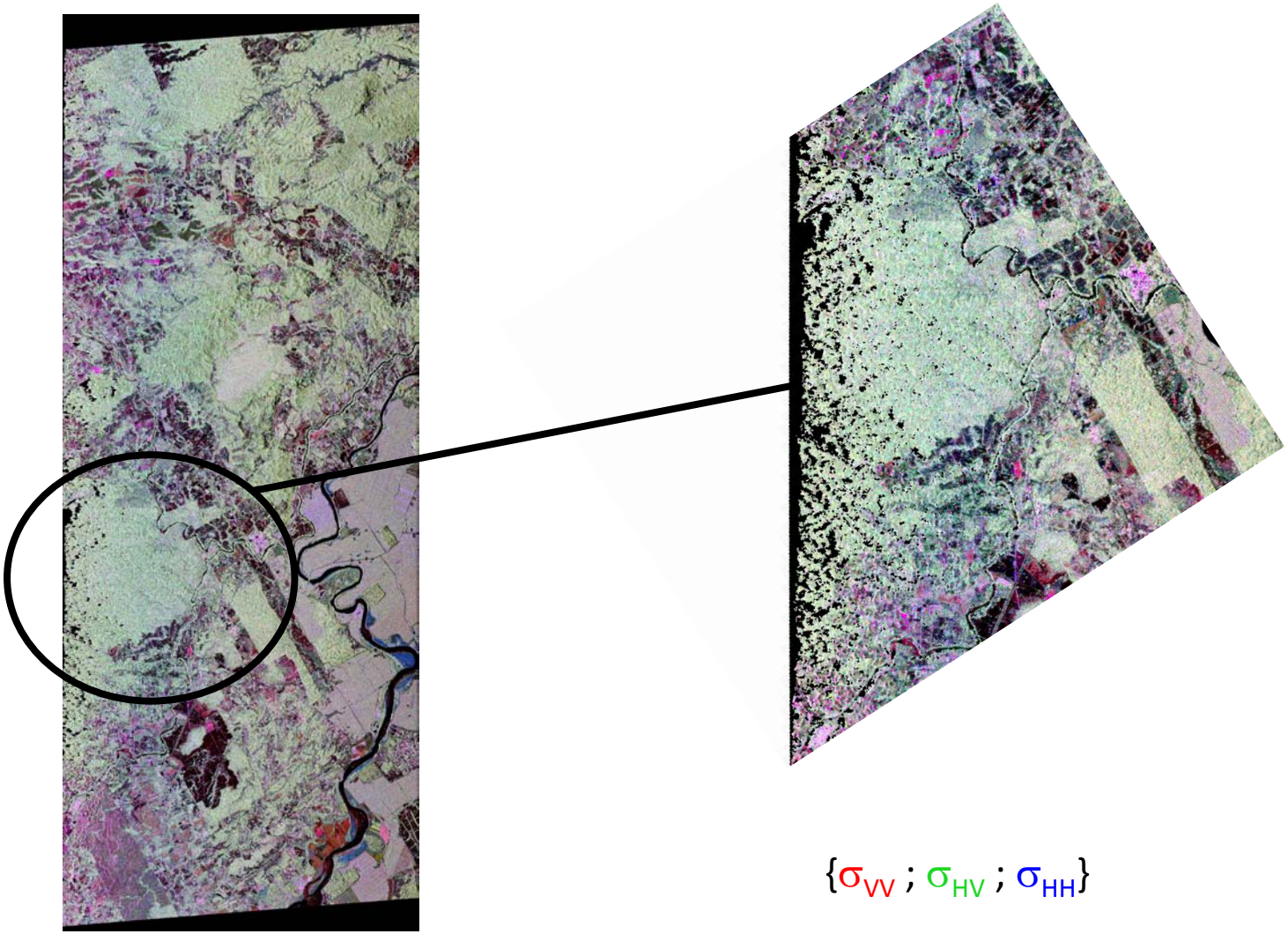


0 < d < 75 m

Mean(d) = 50 cm

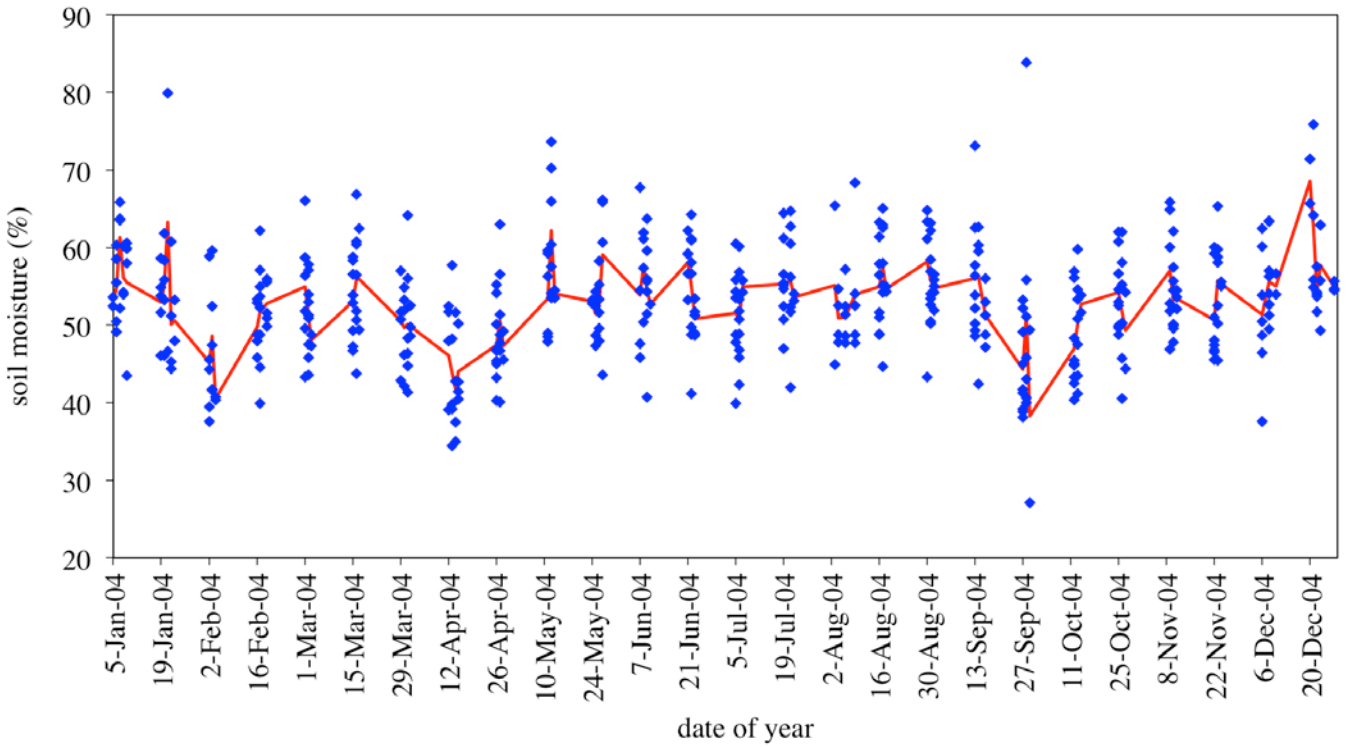
La Selva – Costa Rica

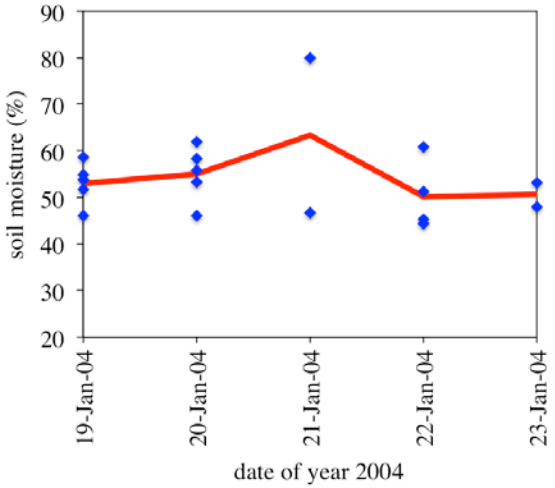
AirSAR data - La Selva - Costa Rica – March 6th, 2004



$\{\sigma_{VV} ; \sigma_{HV} ; \sigma_{HH}\}$

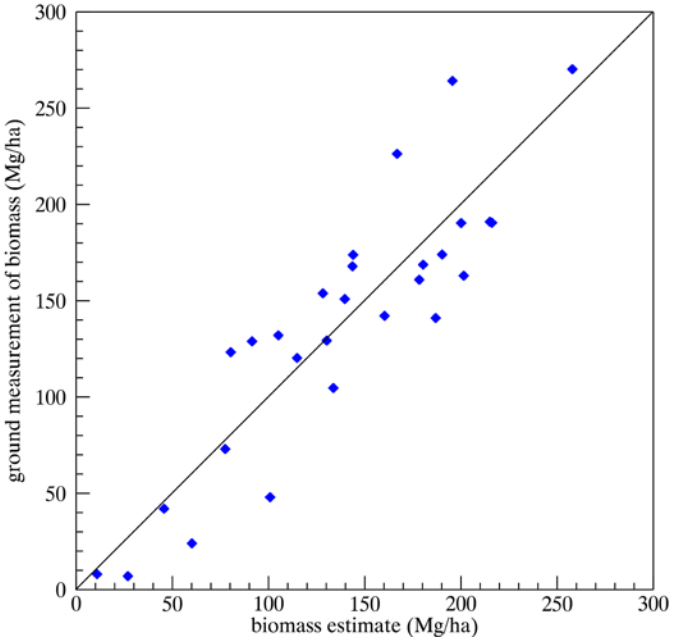
La Selva volumetric soil moisture in 2004



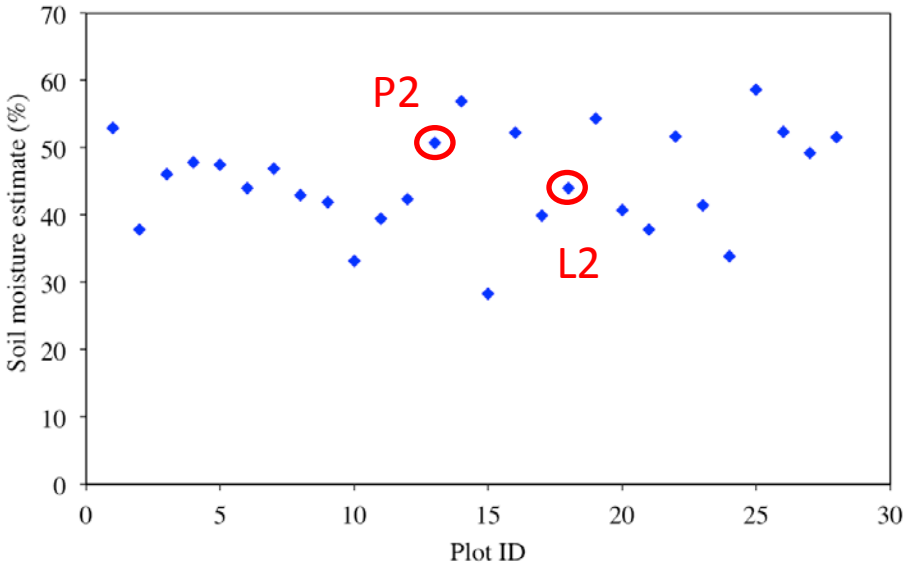


Courtesy of Dr. Diego Dierick for providing the data

Results on tropical forest - La Selva/Costa Rica



RMSE = 30.5 Mg/ha



28.3 % < m_v < 58.7 %

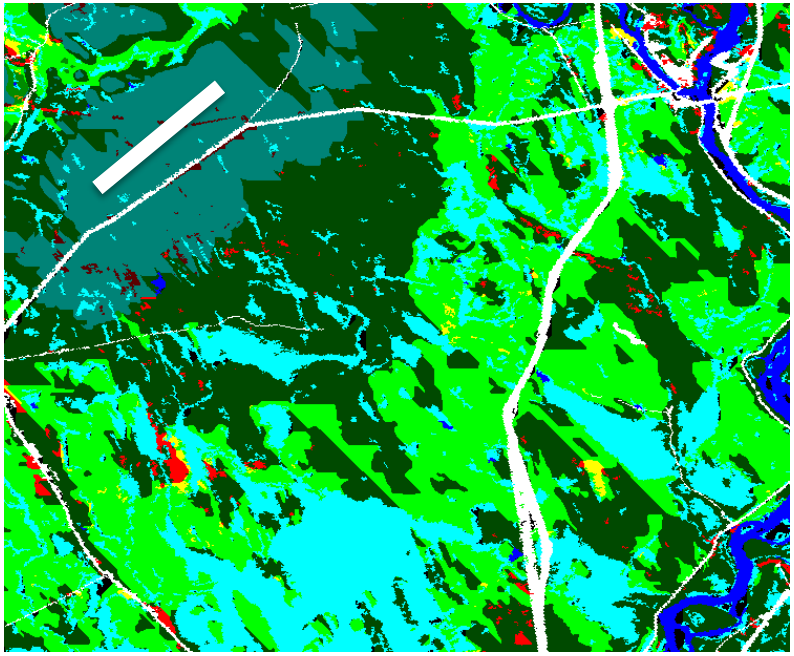
Average(m_v)=45.2 %

P2: m_v = 48.8%, m_v'= 50.8%

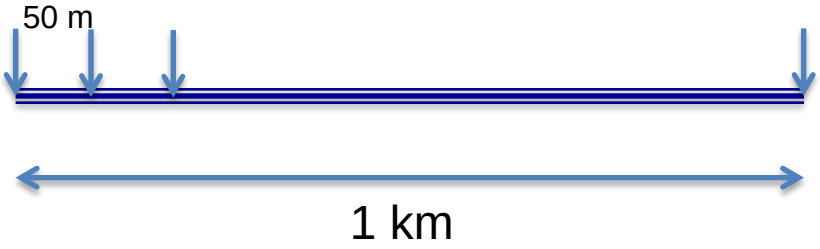
L2: m_v = 47.4%, m_v'= 43.9%

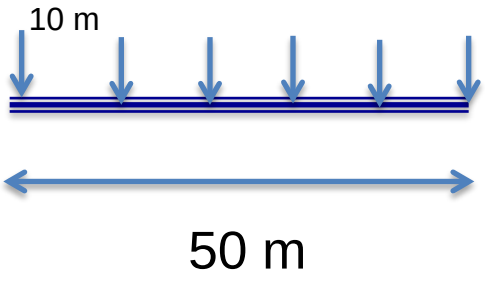
Field campaigns

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

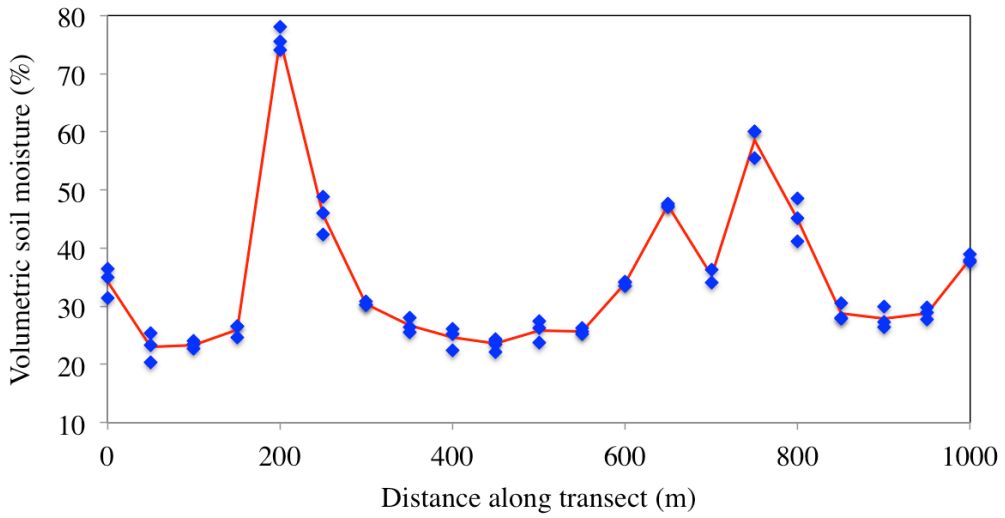
Soil Moisture TDR Sensors

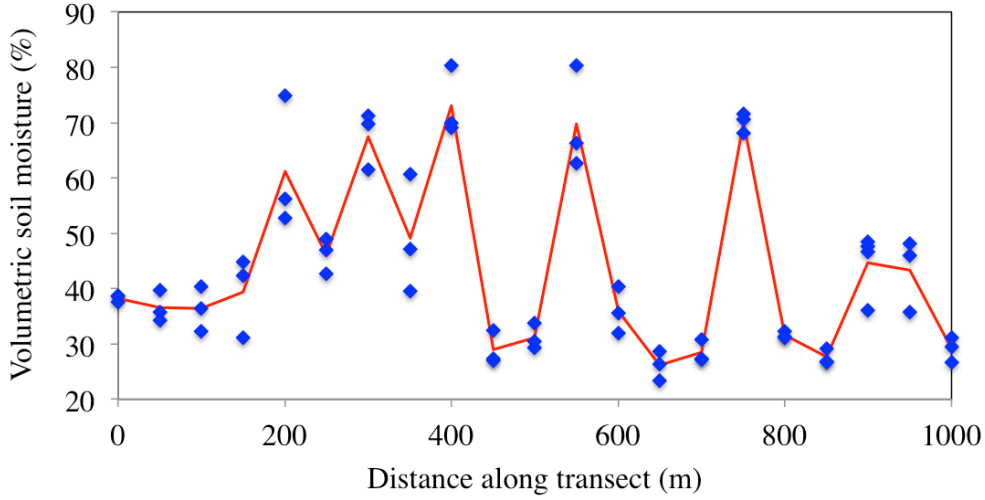
2 units

6050X1 TRASE SYSTEM I

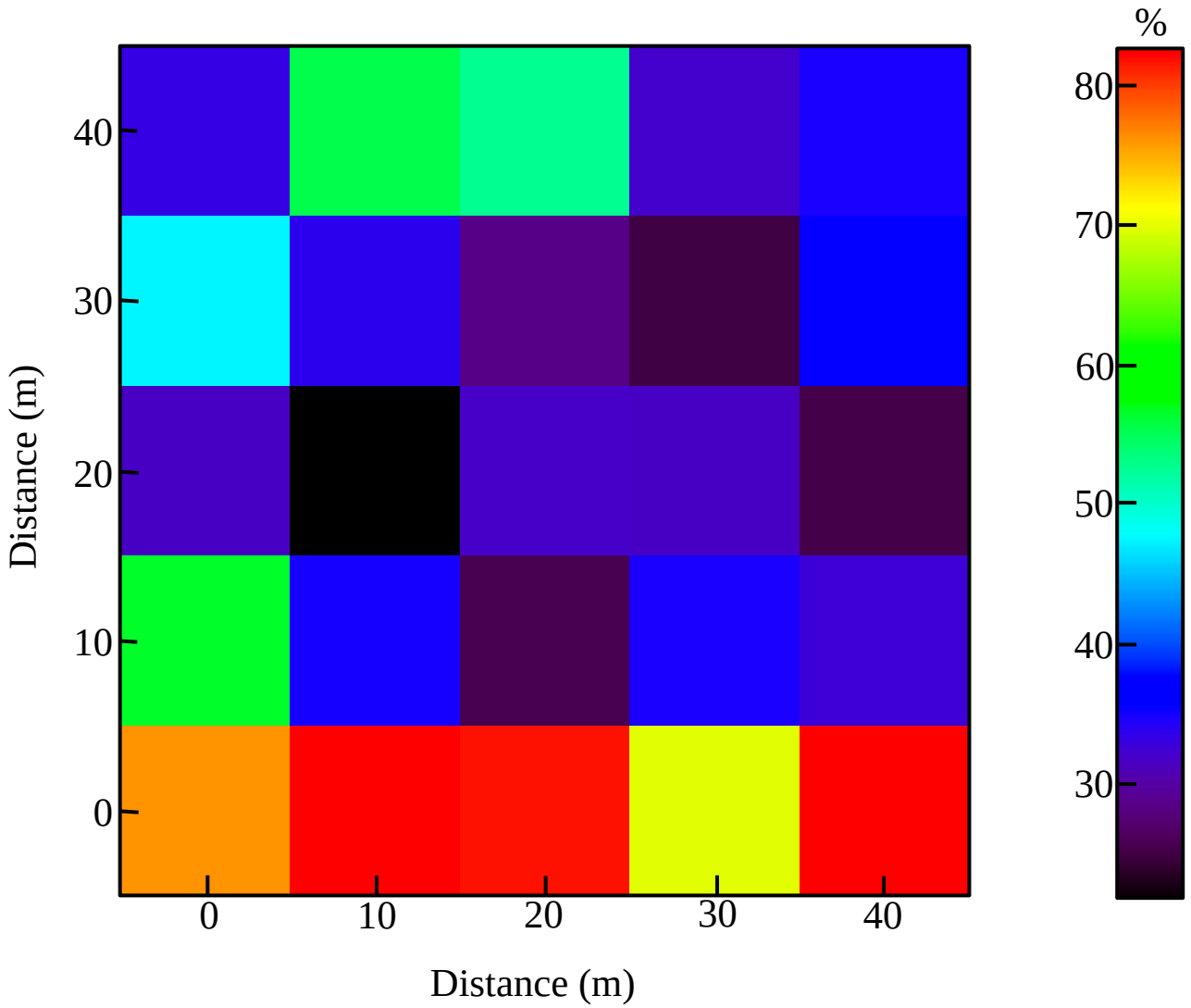
Soil Moisture TDR Sensors

Field measurements examples





Spatial variation of soil moisture



Summary & Perspectives

- Semi-empirical model
  - Is a simplification of the distorted Born model
  - Requires ground measurements to set up calibration coefficients
  - Is sensitive to:
    - Biomass
    - Soil moisture
    - Incidence angle

- Inversion process
  - Uses LM method to invert the forward model
  - Needs initialization and constraints
  - Shows good results over simulated data
    - Biomass: RMSE = 50Mg/ha for a biomass level up to 500 Mg/ha
    - Soil moisture: RMSE = 4.35% for soil moisture up to 40%
  - Estimates soil moisture and biomass with AirSAR P-band data acquired over
    - Howland forest in October 1994 with an absolute error of 3%.
    - La Selva forest in March 2004 with a RMSE of 30.5 Mg/ha for a biomass level up to 300 Mg/ha and soil moisture in the expected range.

- Field measurements show the spatial variation of soil moisture.

- Future works: topographic effect, using AirMOSS SAR data

Acknowledgements

Many thanks to Dr. Sassan Saatchi and Dr. Sermsak Jaruwatanadilok