



MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Biomass Estimation Using Interferometric Height (Dual Frequency InSAR) and P-Band Radar Backscatter

Dutra, Freitas, Mura, Santos and Gama;

Elmiro, Araujo, Sant'Anna and Neeff

DPI and DSR - INPE 2000-2010

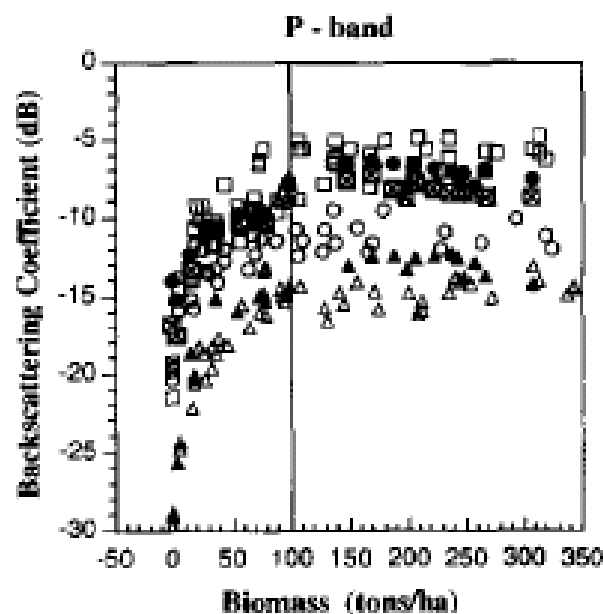
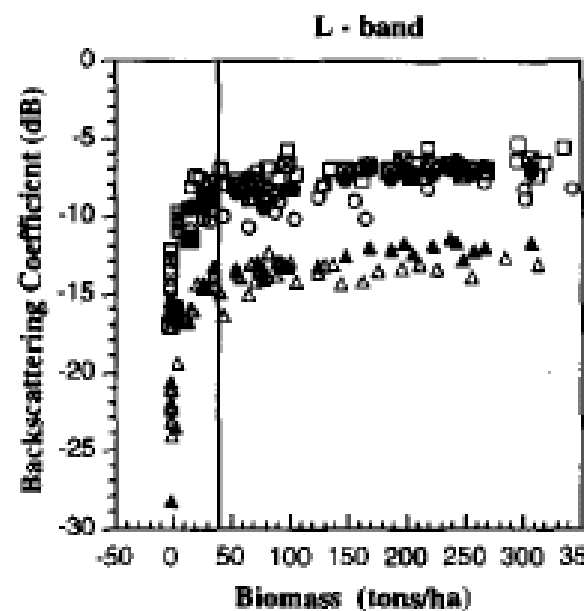
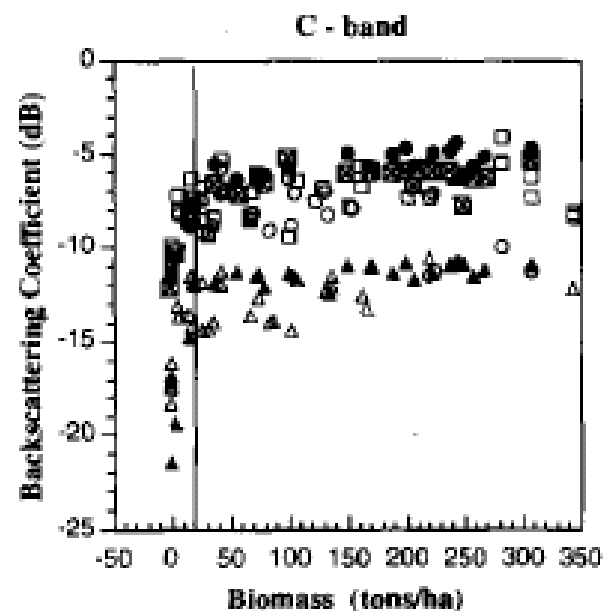


Motivation

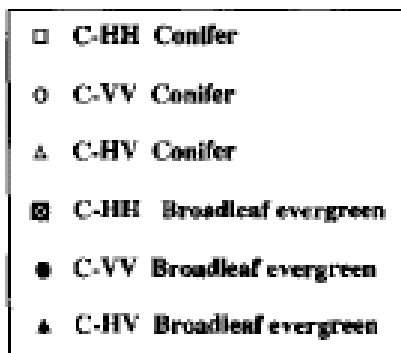
- Global climate change.
 - International agreements require carbon accounting;
 - Key point: Forest biomass estimation;
- Traditional forest inventories: high costs, specially in the tropics
 - Large geographic areas with difficult terrain;
- Remote sensing is an important tool for tropical forest measurements;
- Cloudy tropical environments: Radar is a powerful option for remote forest management;
- *Traditional: Biomass retrievals based only on radar backscatter have the effect of saturation for high biomass stocks;*
- *The saturation effect is particularly pronounced at higher frequencies, but even for P-band has a saturation point of 100-200 t/ha (Imhoff, 1995, Santos et al., 2003).*



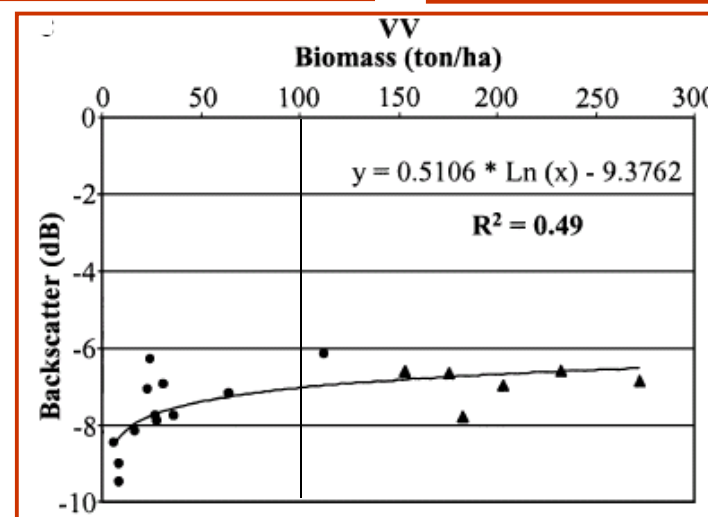
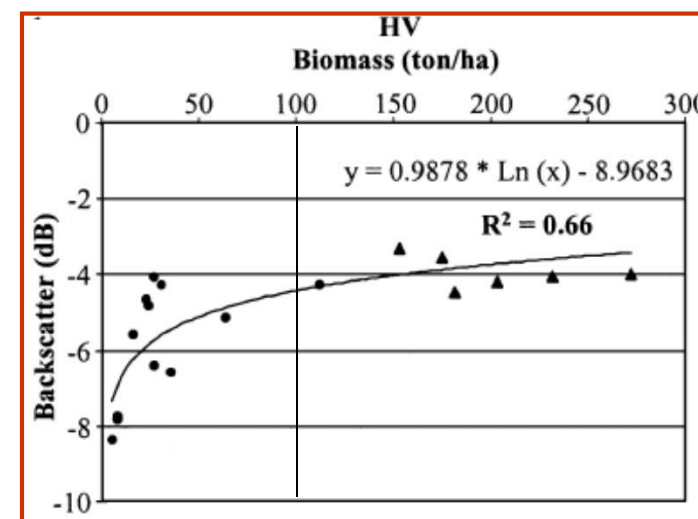
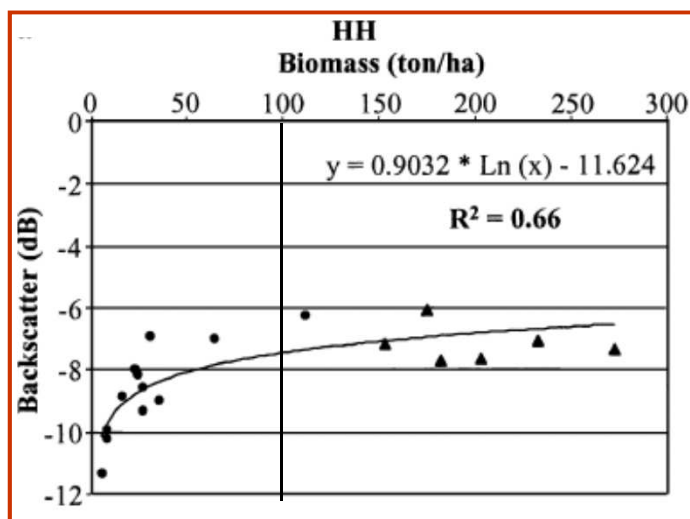
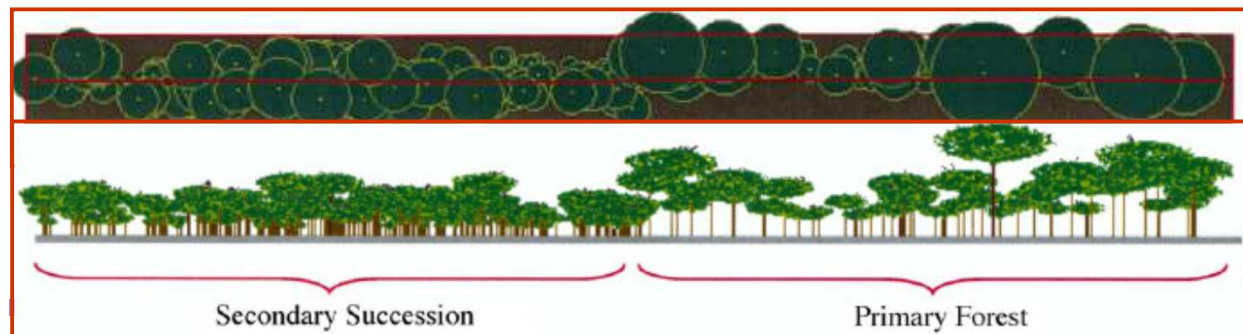
SAR Backscatter x Biomass



Broadleaf Evergreen and Coniferous Forest



Imhoff, 1995



- ▲ Primary forest
- Secondary succession

P-band x Biomass

Tapajós National Forest Pará State, Brazil

Santos et al., 2003



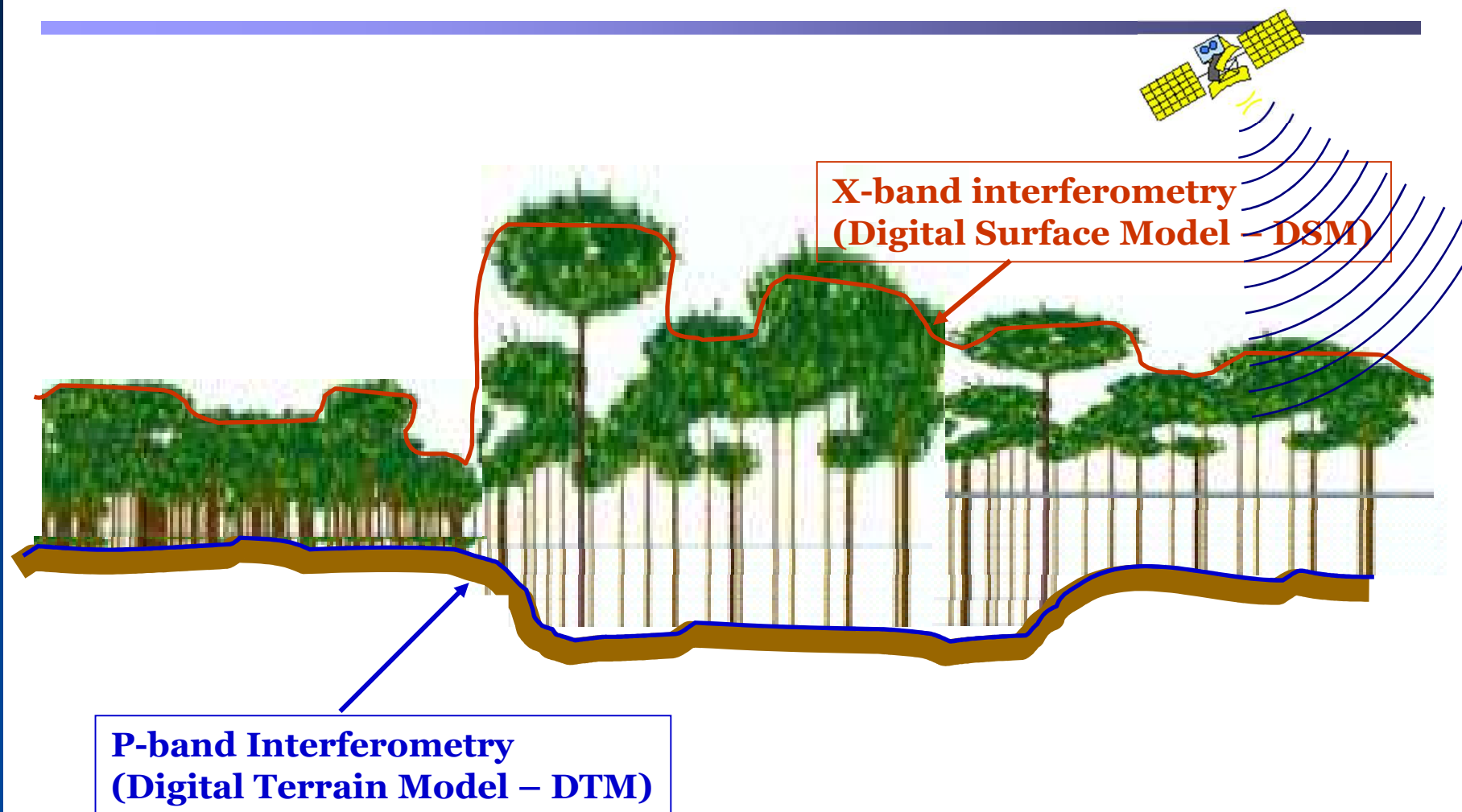
Biomass Estimation

To overcome these limitations, more advanced radar techniques have been suggested, like the use of interferometric SAR for forest structure and biomass estimation (Treuhft and Siqueira (2004), with

- multiple baselines (Treuhft and Siqueira 2000),
- multiple polarizations (Papathanassiou and Cloude 2001),
- the use of the coherence techniques (Hyypä et al. , 2000)
- integration of both intensity and coherence data (Koskinen et al., 2001)
- **multiple frequencies**

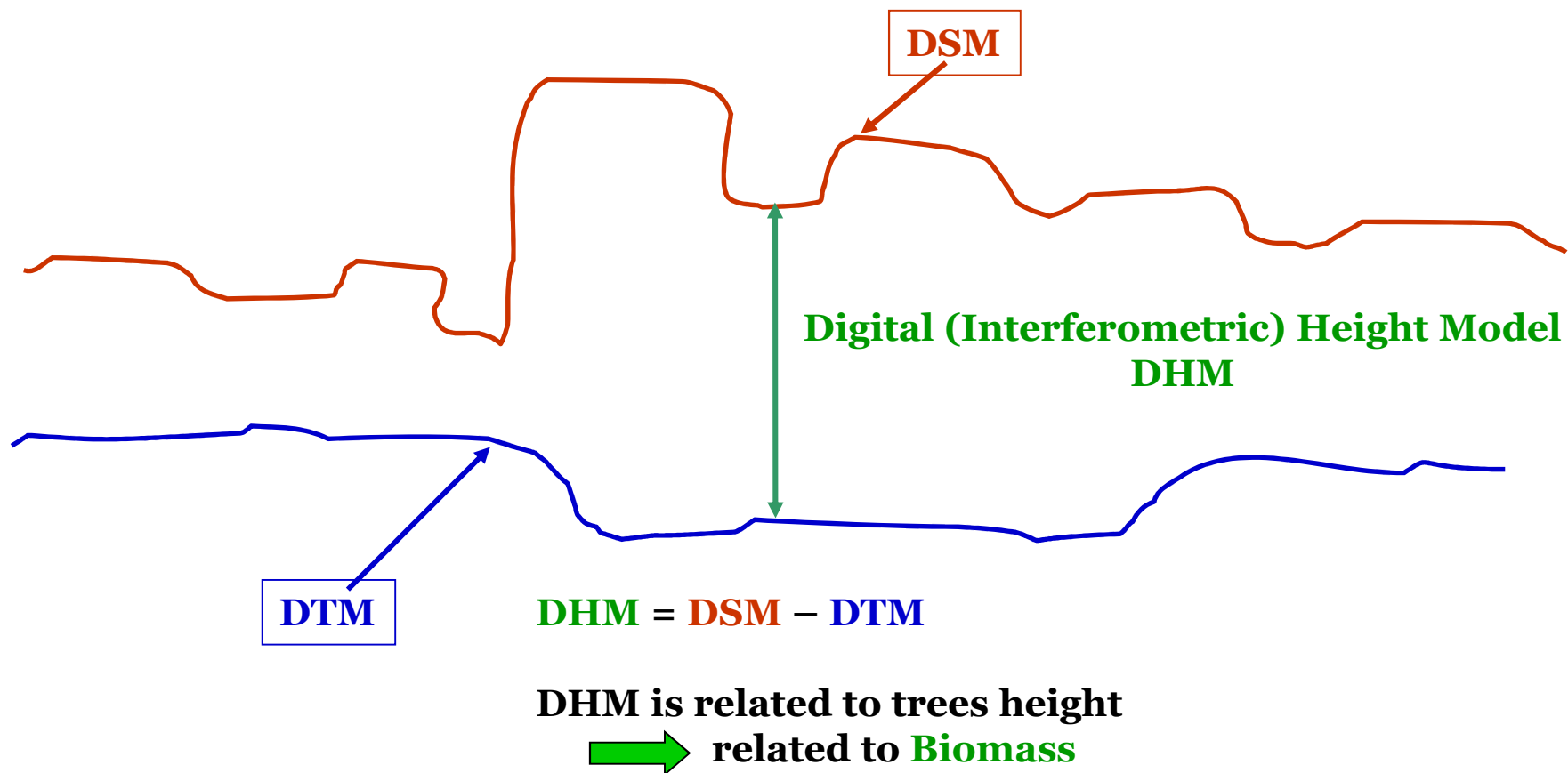


Biomass Estimation with Multiple Frequencies -





Biomass Estimation with Multiple Frequencies



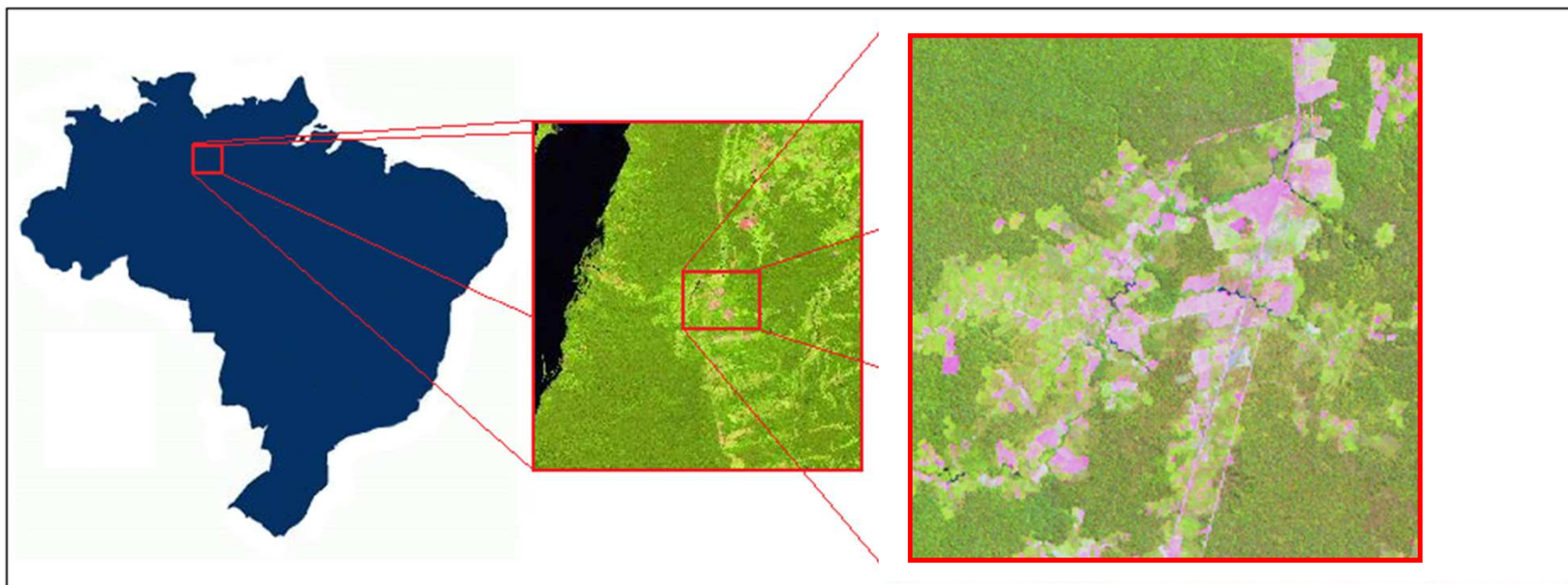


Objective

- Quantify biomass in tropical forest using interferometric vegetation height (obtained by the difference between X- and P bands DEMs), and P-band backscatter coefficient.



Study Area: Tapajós Nacional Forest





Primary Forest



Biomass ~ 150 – 350 ton/ha



Secondary Succession



Biomass $\sim 5 - 100$ ton/ha



Field Data

Field measurements on Primary and Secondary Forest included:

- Tree positions;
- Species;
- DBH and total tree heights for all trees with
 - DBH > 5 cm for secondary succession and
 - DBH > 10 cm for primary forest;

These measurements were performed in an area of :

- 1000 m² (10m x 100m) for secondary succession
- 2500 m² (25m x 100m) for primary forest.

Biomass was estimated using allometric equations:

- Nelson et al. (1999) for secondary succession, and
- Chambers et al. (2001) for primary forest.



Radar Data (Former AeroSensing, now Bradar)

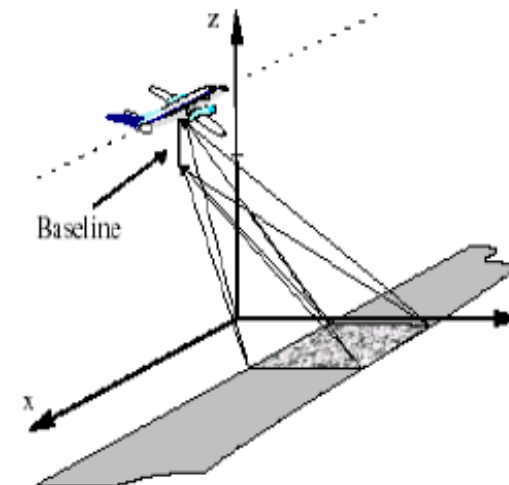
Wavelength: 72 cm (P-band);
3.1 cm (X- band)

Frequency: 415 MHz (P-band);
9.6 GHz (X- band)

Polarization: P-band : HH, HV, VH and VV;
X- band : HH

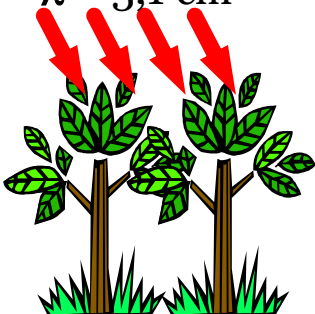
Depression Angle: 45°;

Flight Average Height: 3,216 m;



X Band

$\lambda = 3,1 \text{ cm}$



P Band

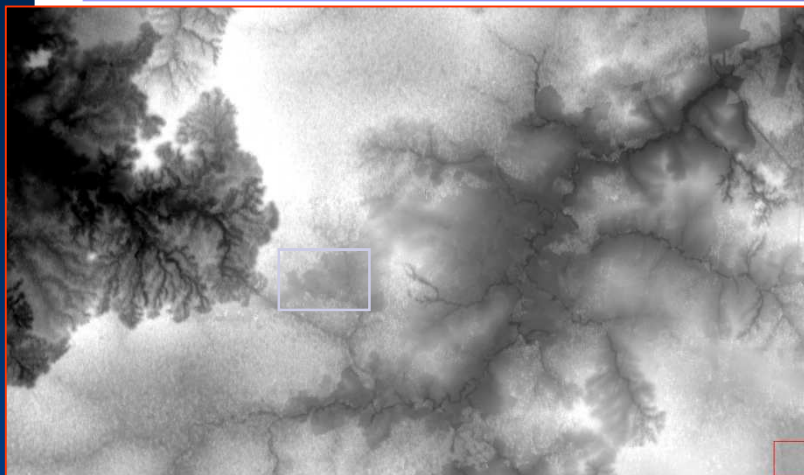
$\lambda = 72 \text{ cm}$



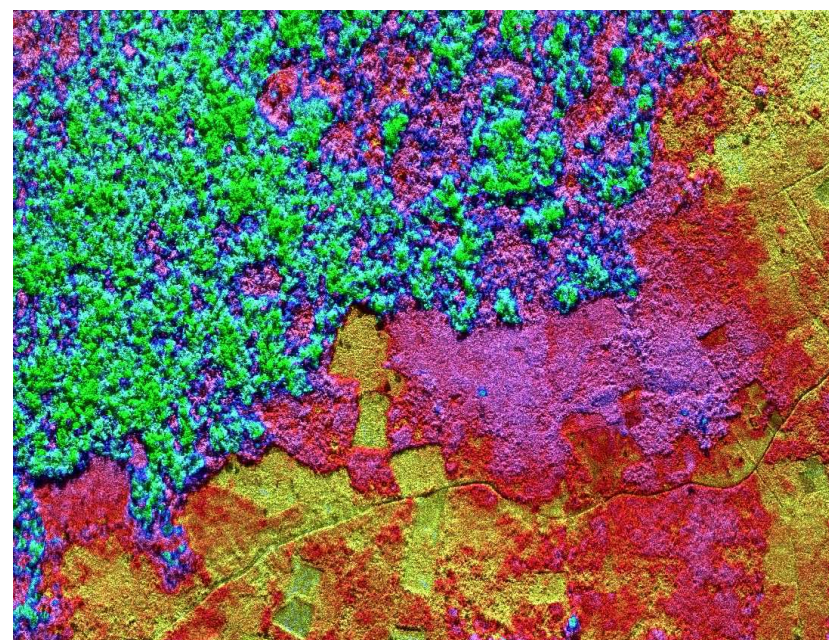
Source: Moreira (1996)



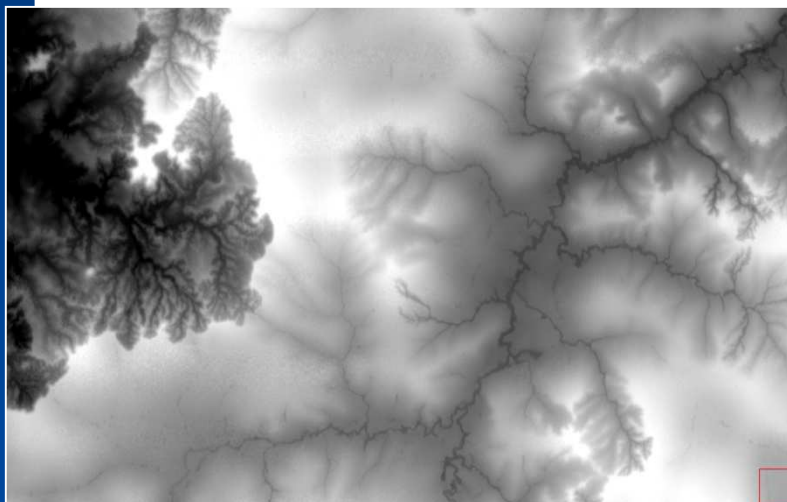
Digital Height Model.



Tapajós National Forest, Pará State
<- X band: 2.5 m surface elevation



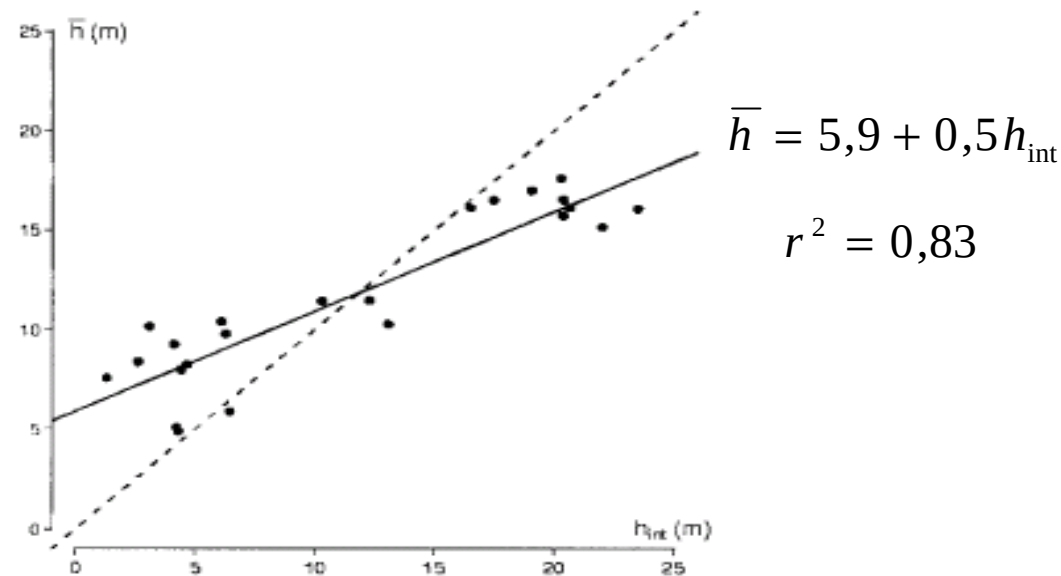
0.3 m 30.0 m
DHM (X-P) as color info + X
band image as Brightness info.



<- P band: 2.5 m ground level



Interferometric Height x Mean Forest Height

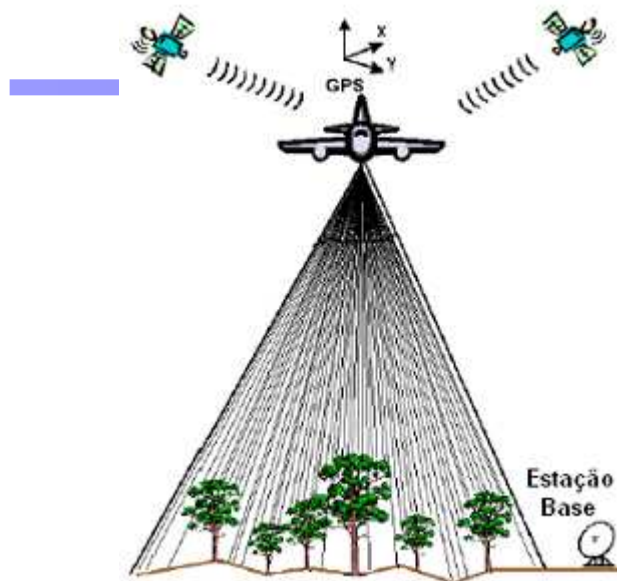


Interferometric Height is higher than average height for primary forest.

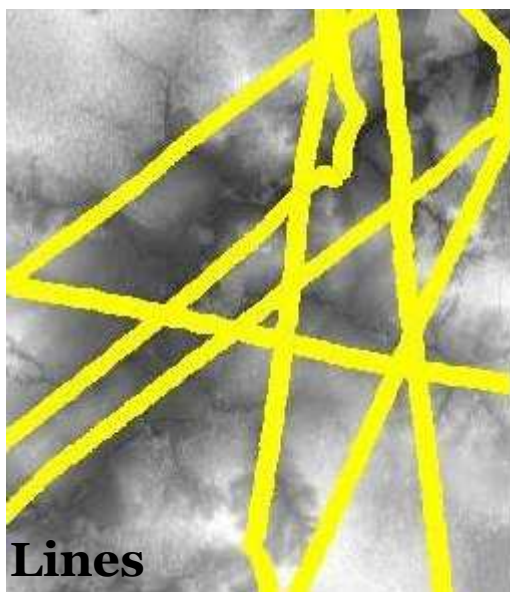
Interferometric Height is lower than average height for secondary forest.



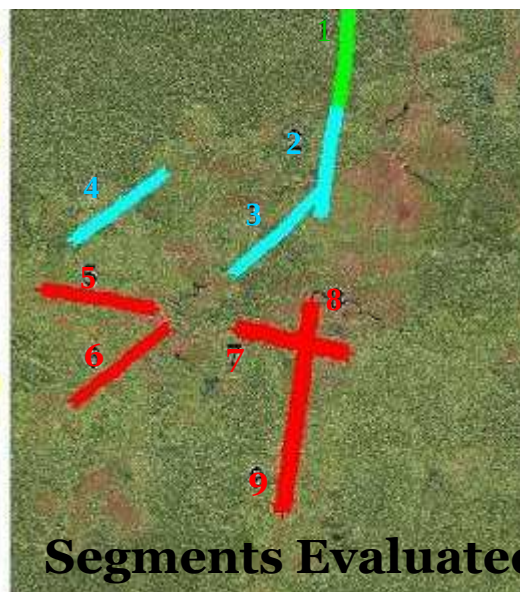
P- and X-band DEM vs Lidar (filtered)



Perfil LIDAR R	Ground Min LIDAR – P band DEM			Top Max LIDAR – X-band DEM		
	Average	MAE	RMSE	Average	MAE	RMSE
1	2.40	1.10	1.25	3.04	1.33	1.63
2	1.62	0.89	1.09	2.06	1.51	1.82
3	1.60	1.03	1.21	2.23	1.46	1.76
4	1.56	0.98	1.14	2.17	1.53	1.88
5	0.82	1.07	1.25	1.96	1.38	1.67
6	1.13	0.94	1.13	1.75	1.51	1.81
7	0.86	1.03	1.21	1.69	1.45	1.77
8	1.10	0.96	1.12	1.81	1.56	1.88
9	0.90	1.08	1.26	1.97	1.34	1.64



Lines



Segments Evaluated

**Small spot lidar
(Hess et al,
2002)**

**Comparison:
(Elmiro et al,
2006,2008)**



P- and X-band DEM vs Lidar

P-band DEM

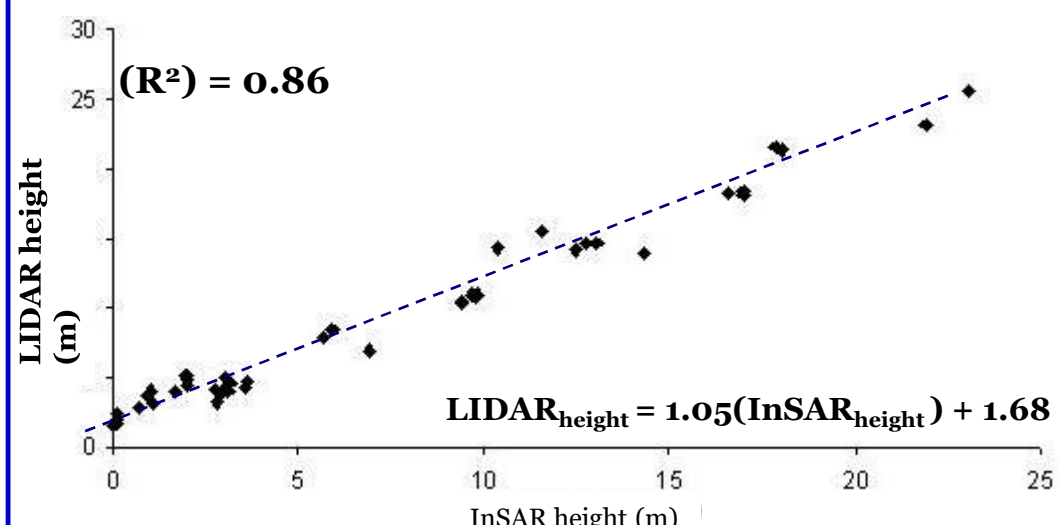
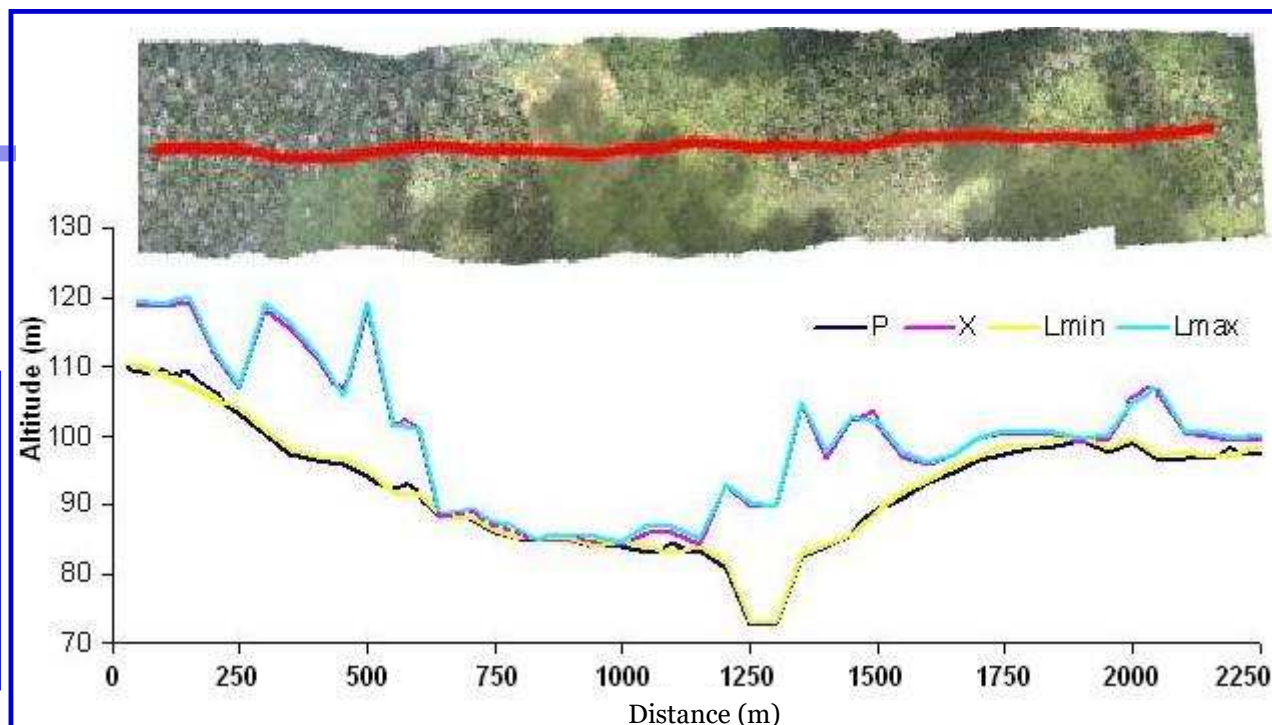
RMSE and MAE $\cong$ 1 to 1.5 m
Average difference $\cong$ 1.3 m
LIDAR has less penetration

X-band DEM

RMSE and MAE $\cong$ 1 to 2.0 m
Average difference $\cong$ 2 m
LIDAR top of canopy.
InSAR 'average' of canopy.

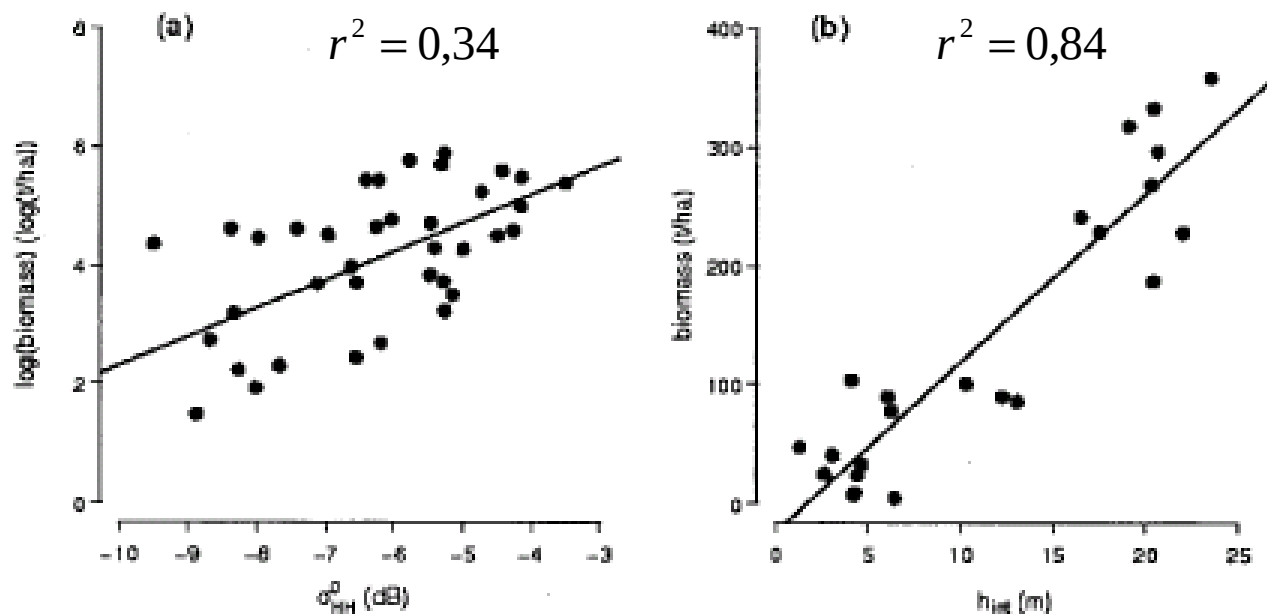
Vegetation Height

Slope $\cong$ 1, good agreement between
LIDAR and InSAR heights
Intercept $\cong$ 1.7, indicates
LIDAR height $\cong$ > InSAR height





Biomass x Interferometric Height and σ_{HH}^0



$$\text{Biomass} = 44.965 + 13.87h_{int} + 10.566\sigma_{HH}^0$$

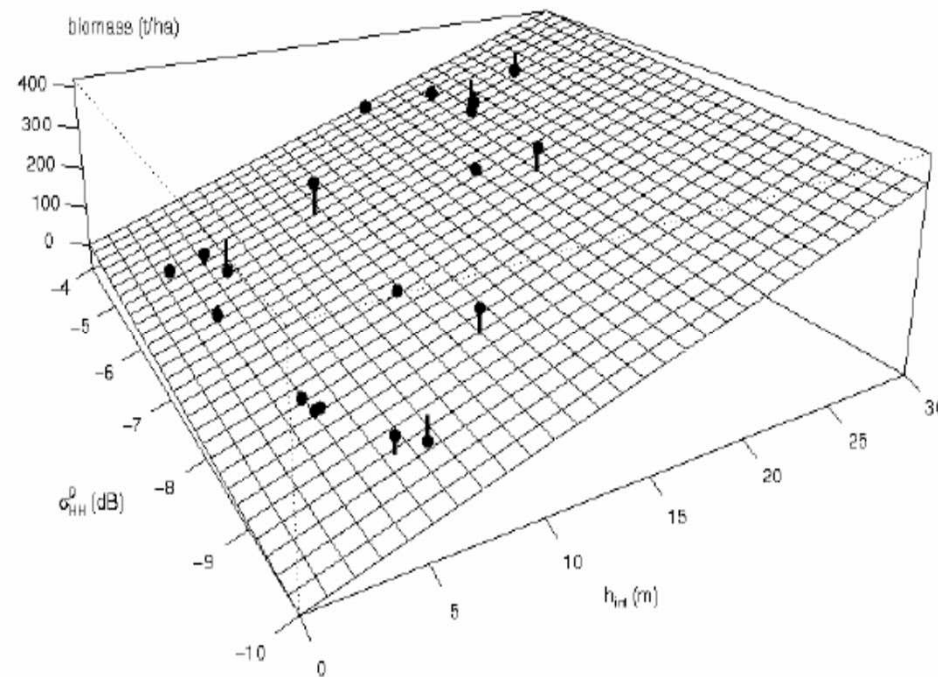
$$r^2 = 0,89$$



BIOMASS as multiple regression

$$biomass = 44.965 + 13.887 \cdot h_{int} + 10.556 \cdot \sigma_{0HH},$$

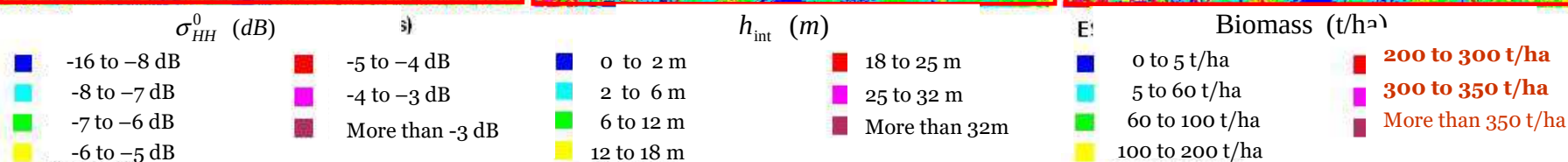
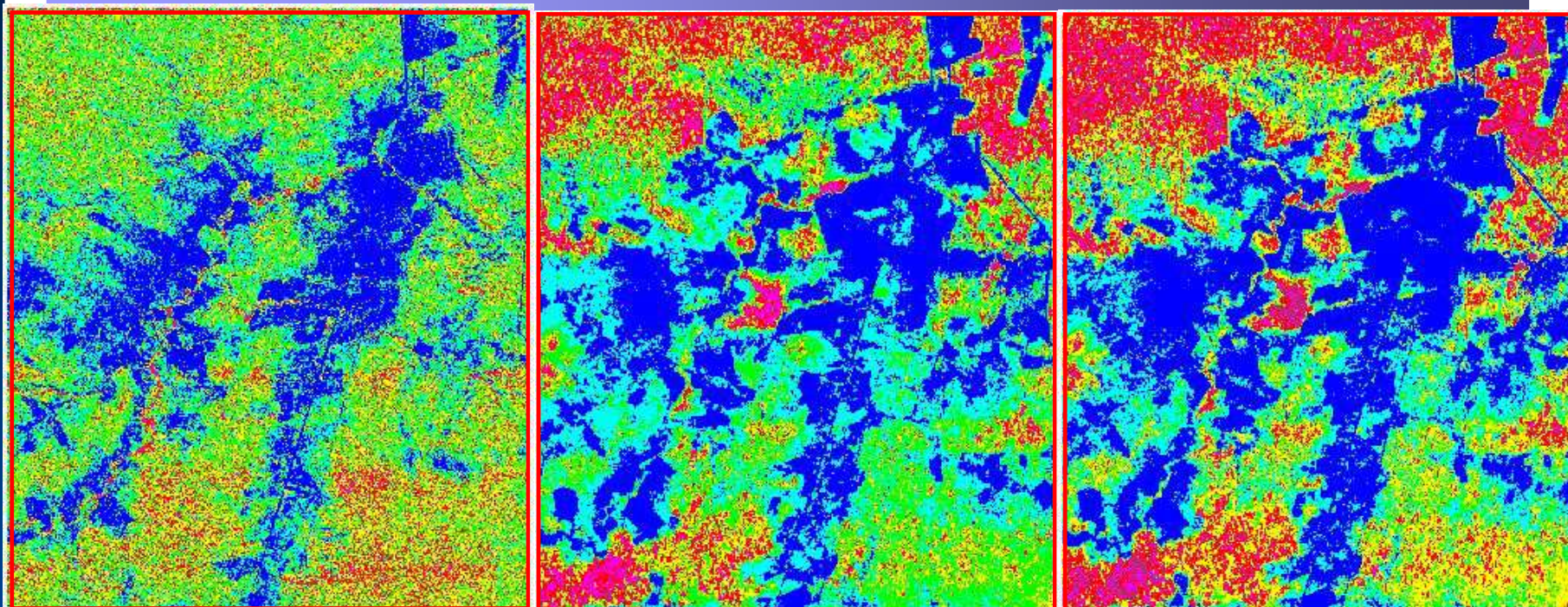
(std. error) (58.3) (1.6) (7.2)



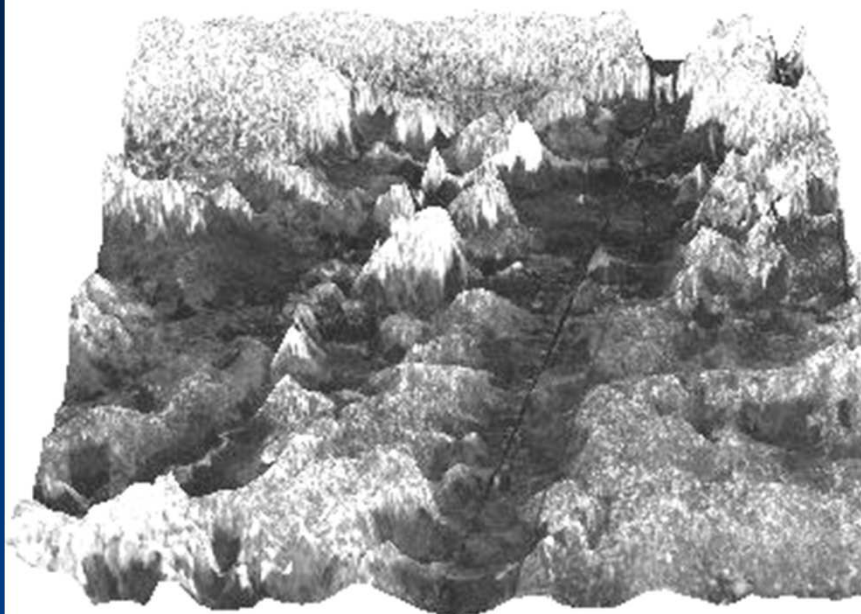
$$r^2 = 0,89$$



Biomass x Interferometric Height and σ_{HH}^0



$$10.57 \times \sigma_{HH}^0 + 13.87 \times h_{int} + 44.97 = \text{Biomass}$$



Estimativa da Biomassa



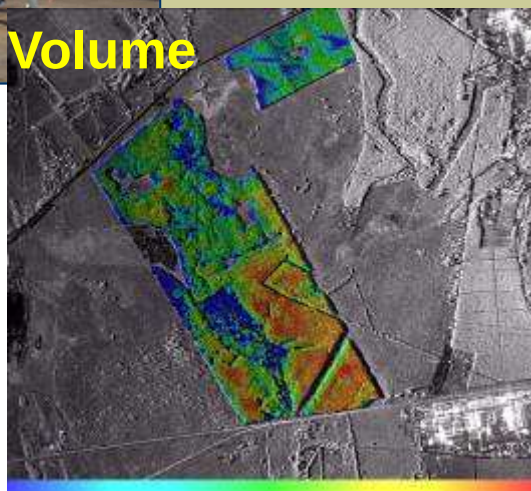
Desvio Padrão da Estimativa de Biomassa

- Average prediction error of 46.1 t/ha.
- The uncertainties of the estimation, measured by the standard deviation of estimates, are usually higher for lower values of biomass.

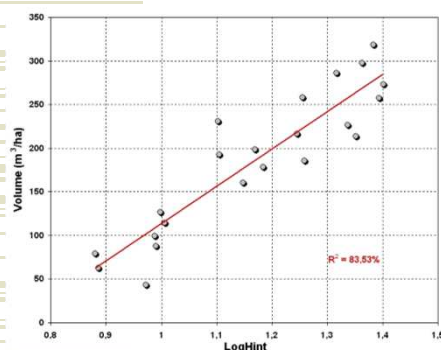
BIOPHYSICAL PARAMETERS ESTIMATION OF EUCALYPTUS STANDS USING MULTIPLE FREQ InSAR



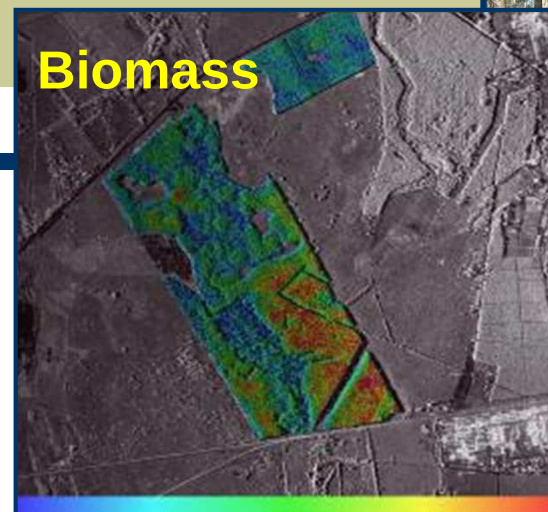
Volume



**0,0
m³/ha.**



Biomass

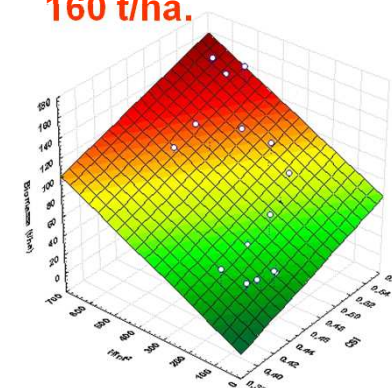


**325
m³/ha.**

0 t/ha.



160 t/ha.



	Volume	Biomass
Variables	LogHint	CSI,Hint²
R²	83,53%	86,29%
R²a	82,7%	84,84%
Prediction errors	10,55%	10,38%

$$CSI = VV/(VV+HH)$$

$$Hint = DEM X - DEM Phh$$



Conclusions

- The P-DEM (DTM) was on average 1.331 m below forest Min_LIDAR, with RMSE of 1.183 m.
- The X-DEM (DSM) was on average 2.074 m below the Max_LIDAR with RMSE of 1.762 m.
- The difference between the DSM and DTM, called DHM, is related to the vegetation height. For large areas usage a refinement procedure to DHM, was necessary to attain the desirable precision within the forest height range.
- *Use of DHM -> Biomass estimation sensitivity goes beyond 200 ton/ha*
- Interferometric height and P-band HH backscatter are useful parameters to estimate biomass. Their relation has a coefficient of determination of 0.89 and prediction error of 46.1 t/ha.
- The uncertainties of the estimation, measured by the standard deviation of estimates, are usually higher for lower values of biomass.



References

Imhoff, M.L. 1995. Radar backscatter and biomass saturation: Ramifications for a global biomass inventory. *IEEE Trans. Geosci. Remote Sens.* 33(2):511–518.

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References

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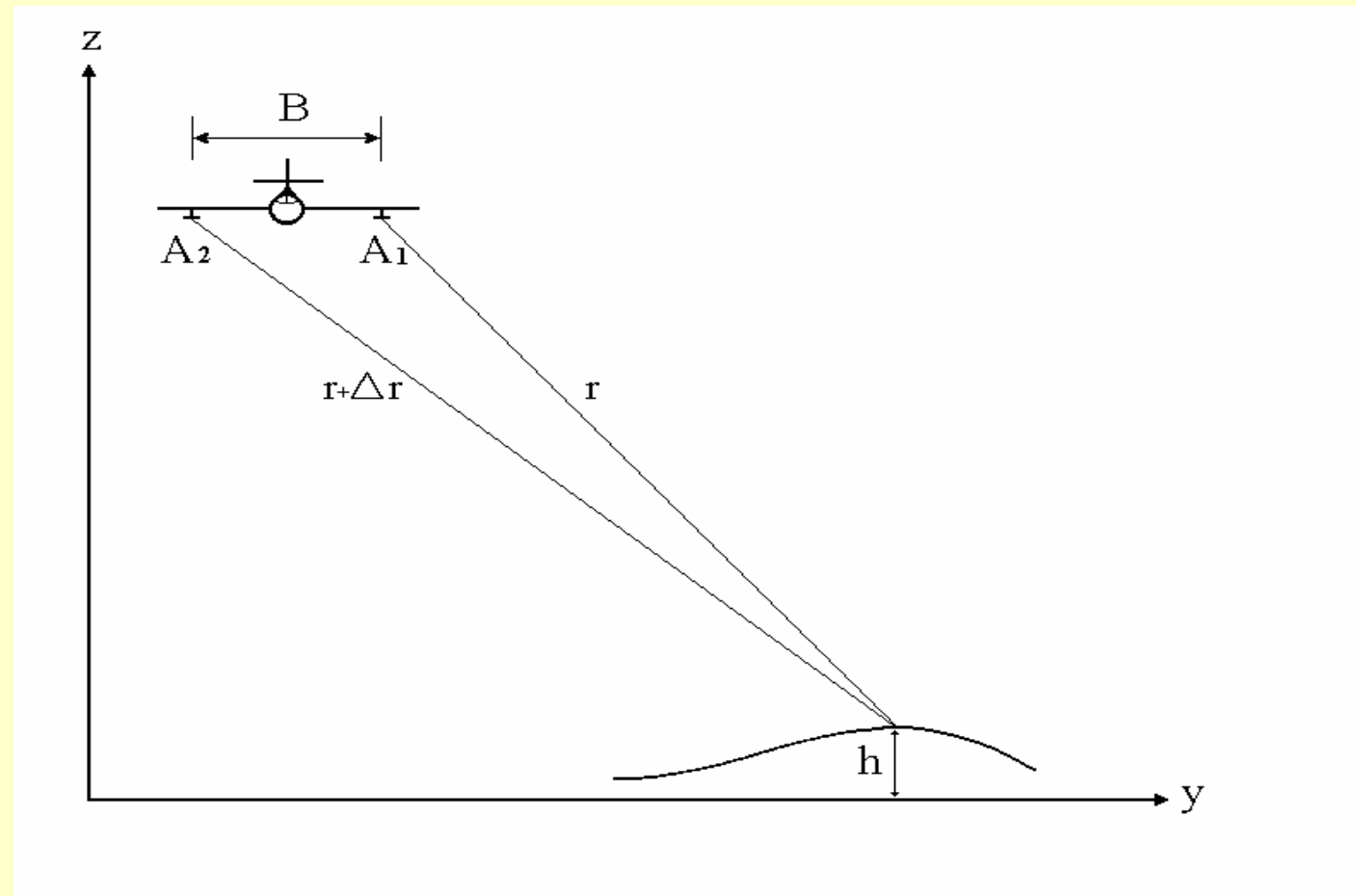
[TIMBÓ ELMIRO, M. A.](#) ; DUTRA, L. V. ; [MURA, J. C.](#) ; [SANTOS, J. R.](#) ; [FREITAS, C. C.](#) . AVALIAÇÃO DE DADOS DE ALTIMETRIA DA FLORESTA AMAZÔNICA BASEADOS NAS TECNOLOGIAS INSAR, LIDAR E GPS. RBC. Revista Brasileira de Cartografia, v. 58, p. 233-246, 2006.

[TIMBÓ ELMIRO, M. A.](#) ; DUTRA, L. V. ; [MURA, J. C.](#) . Altimetry Fitting Methods for INSAR Digital Elevation Models. RBC. Revista Brasileira de Cartografia, v. 60, p. 263-269, 2008



Single Pass SAR Interferometry

$$\Delta\phi = \frac{4\pi\Delta r}{\lambda}$$





InSAR Processing



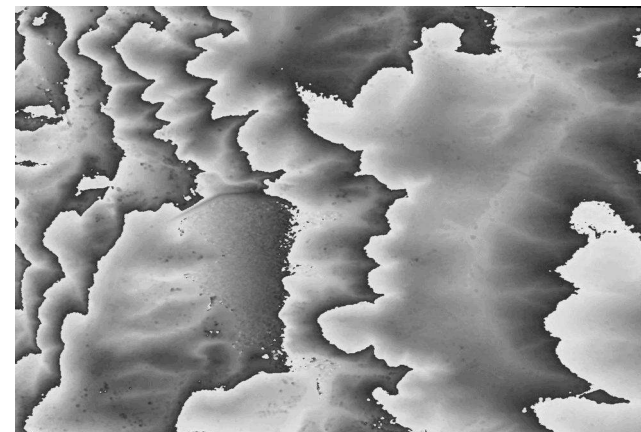
Image 1 I1 (Complex Numbers)



Image 2- I2



$$(I1 \times I2^*)$$



Phase ($I1 \times I2^*$) = Wrapped phase - Hologram



Phase Unwrapping -> Absolute Phase

Phase Unwrapping

