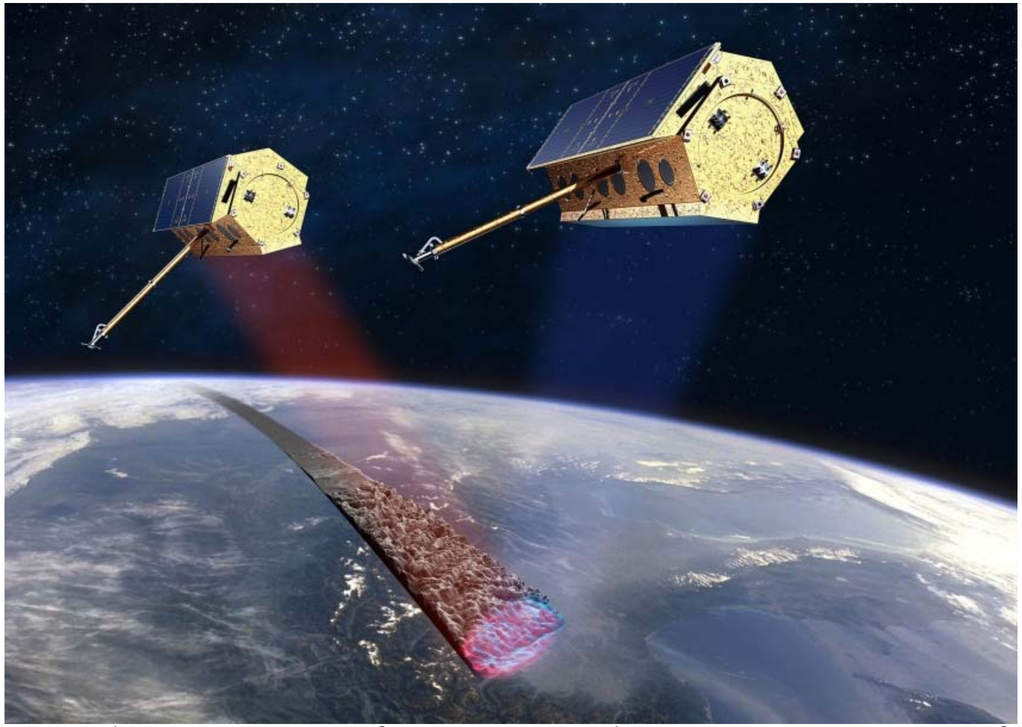
National Aeronautics and Space Administration

Tropical Forest Remote Sensing of Structure and Biomass over Brazil with TanDEM-X



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4th TanDEM-X Science Team Meeting

DLR 12-14 June 2013

Tropical Forest Remote Sensing of Structure and Biomass over Brazil with TanDEM-X

- Motive
- TanDEM-X InSAR, lidar, and field data in Brazil
- InSAR and lidar and the Fourier transform
- Phase and coherence and penetration of TanDEM-X and lidar
- Models
- Next

Tropical Forest Remote Sensing of Structure and Biomass over Brazil with TanDEM-X

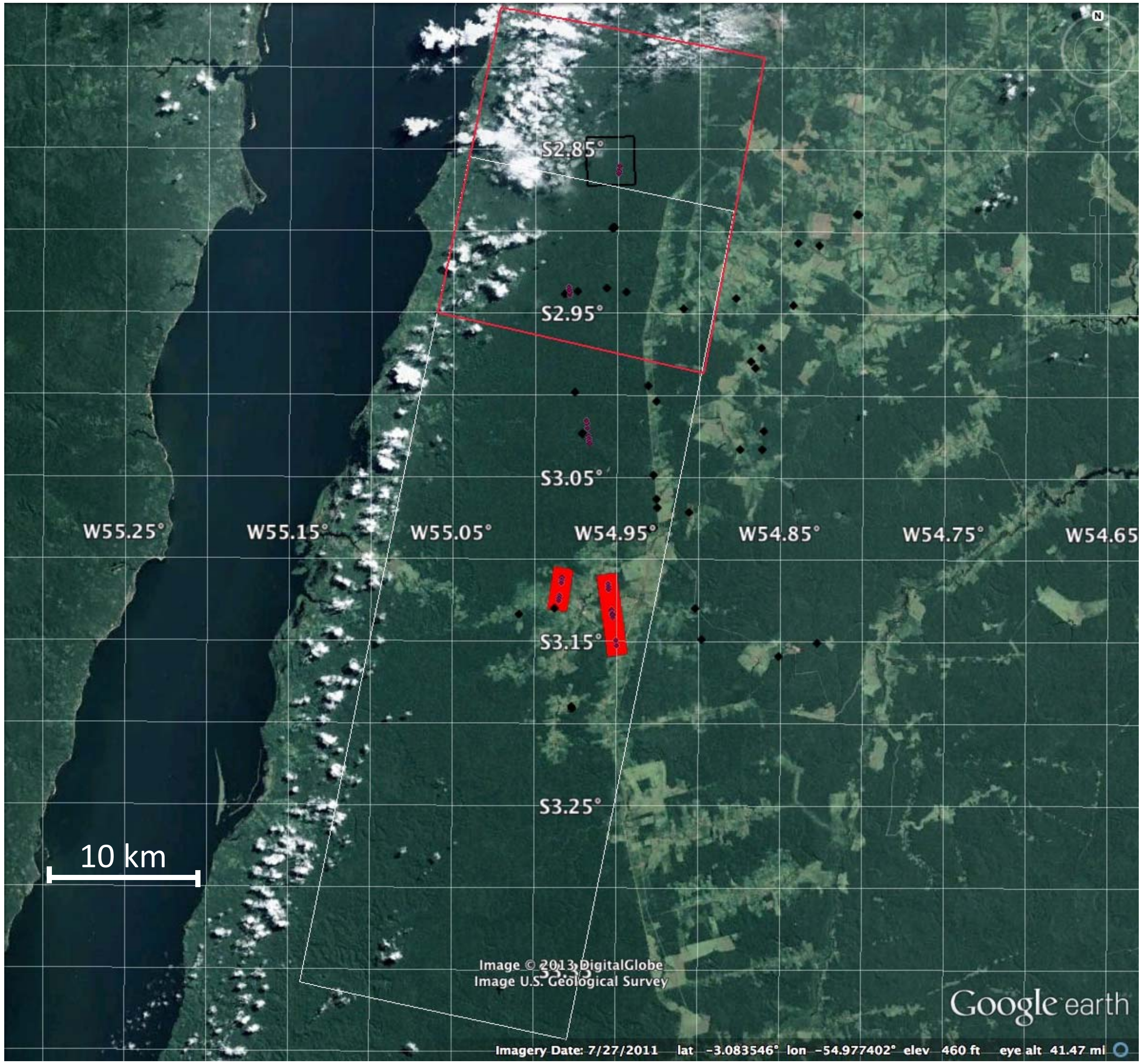
- Deforestation is the second largest anthropogenic contributor to atmospheric CO_2
    - *CO2 emissions from fossil fuel combustion, including small contributions from cement production and gas flaring, were 8.7±0.5 Pg C yr−1 in 2008, an increase of 2.0% on 2007, 29% on 2000 and 41% above emissions in 1990* *(Le Quere 2009)*
    - Our best estimate for 2008 LUC emissions is 1.2 Pg C yr−1 (fire)

- Tropical forests contain about 50% of the Earth's forested biomass, above LUC emissions were dominated by tropical deforestation

- Remote sensing of (tropical) forest structure appears to be necessary for global monitoring of forest biomass (REDD) and the global carbon cycle

- Tropical forests are the most complex remote sensing target in the solar system

InSAR, lidar and field data at Tapajós National Forest



InSAR TanDEM-X at Tapajós

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; <@ <==	>?@A?@A	#'7CD=BE@@L="	. . . .		; BJEBE	BJFA@' "&79P$Q6- R#0	%6K
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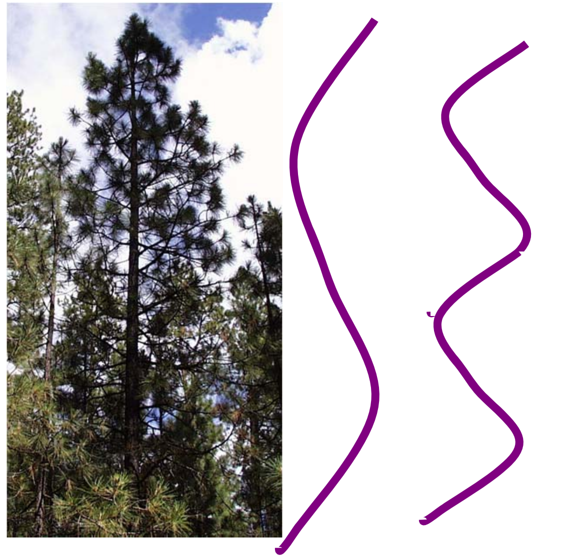
InSAR and lidar and the Fourier Transform



- InSAR complex coherence is the Fourier transform of the radar power in the vertical direction

$$Compl\ \ coherence_{InSAR}(B) = \frac{\int_0^\infty P(z)\ \ e^{i\alpha_z(B)z}\ \ dz}{\int_0^\infty P(z)\ \ \ dz}$$

InSAR
Fourier poor, coverage rich

- Lidar complex coherence is the Fourier transform of the waveform in the vertical direction

$$Compl\ \ coherence_{lidar}(\alpha_z) = \frac{\int_0^\infty w(z)\ \ e^{i\alpha_z z}\ \ dz}{\int_0^\infty w(z)\ \ \ dz}$$

Lidar
Fourier rich, coverage poor

- **Use lidar complex coherence to evaluate potential of InSAR baselines**

Fourier Transform Derivatives

- Derivatives of γ near zero frequency give profile averaged height (‘), profile standard deviation (‘’)…

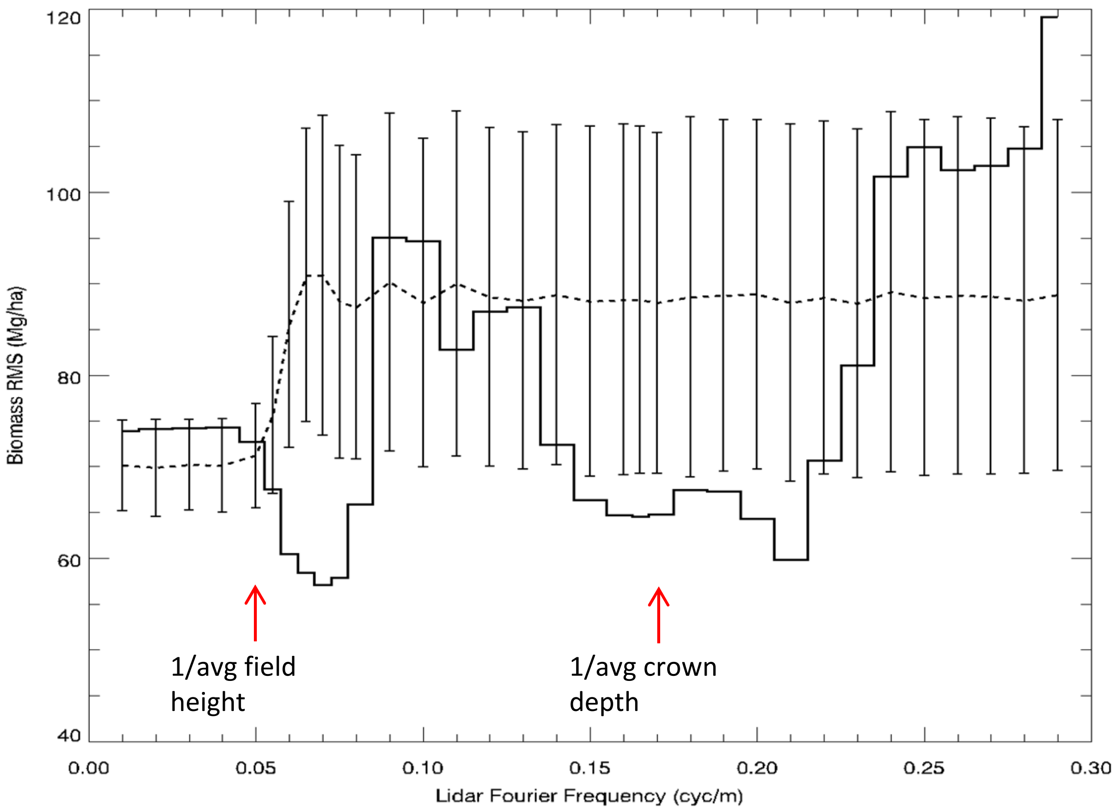
$$\lim_{\alpha_z \to 0} \frac{d\gamma(\alpha_z(B))}{d\alpha_z} = \frac{\int_0^\infty iz\, P(z)\; e^{i\alpha_z z}\; dz}{\int_0^\infty P(z)\; dz} = i\;\bar{z}$$

Biomass Estimation:

What Fourier Frequencies are Used?

InSAR may be Fourier poor,

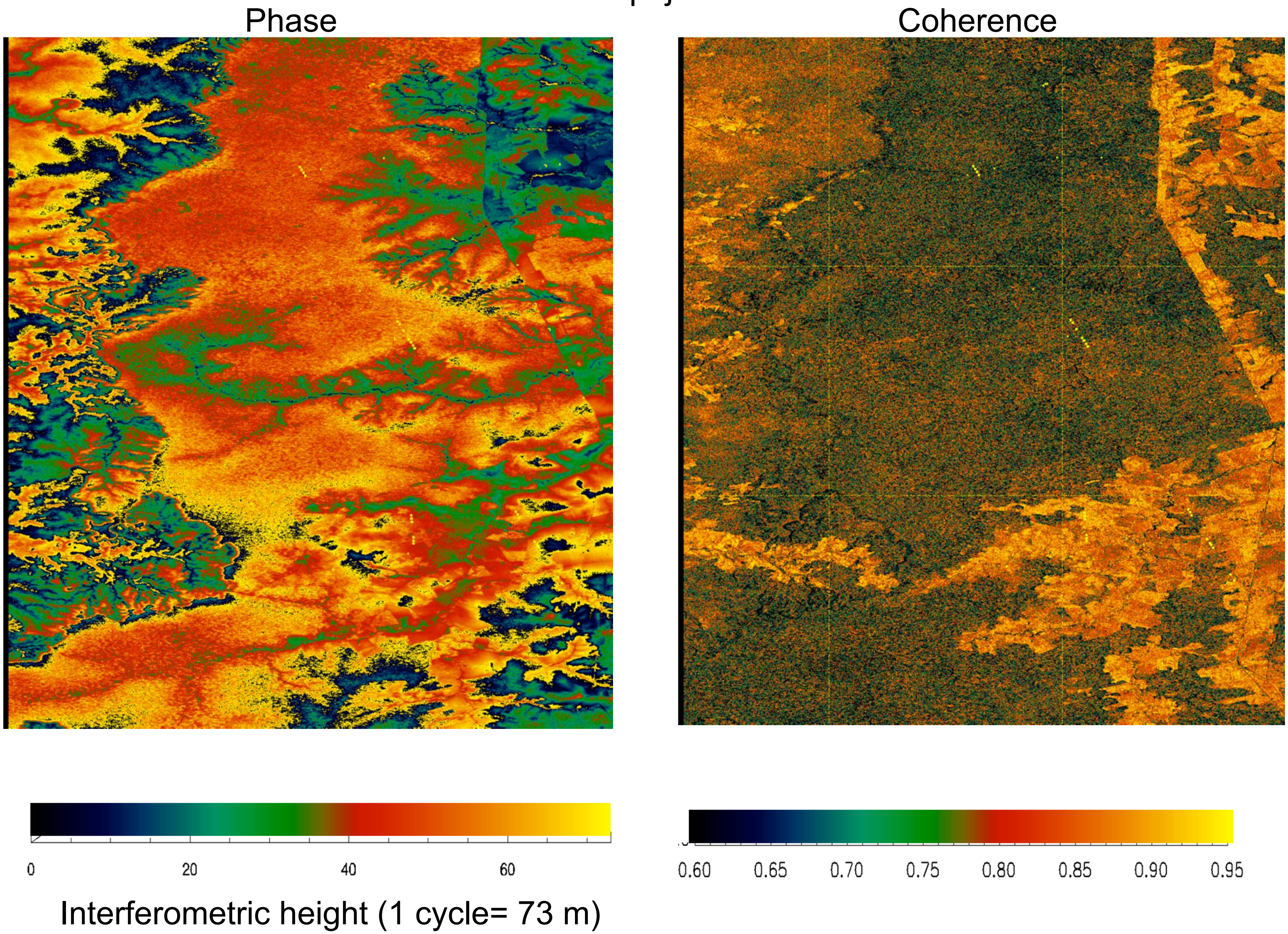
But is it Fourier adequate?



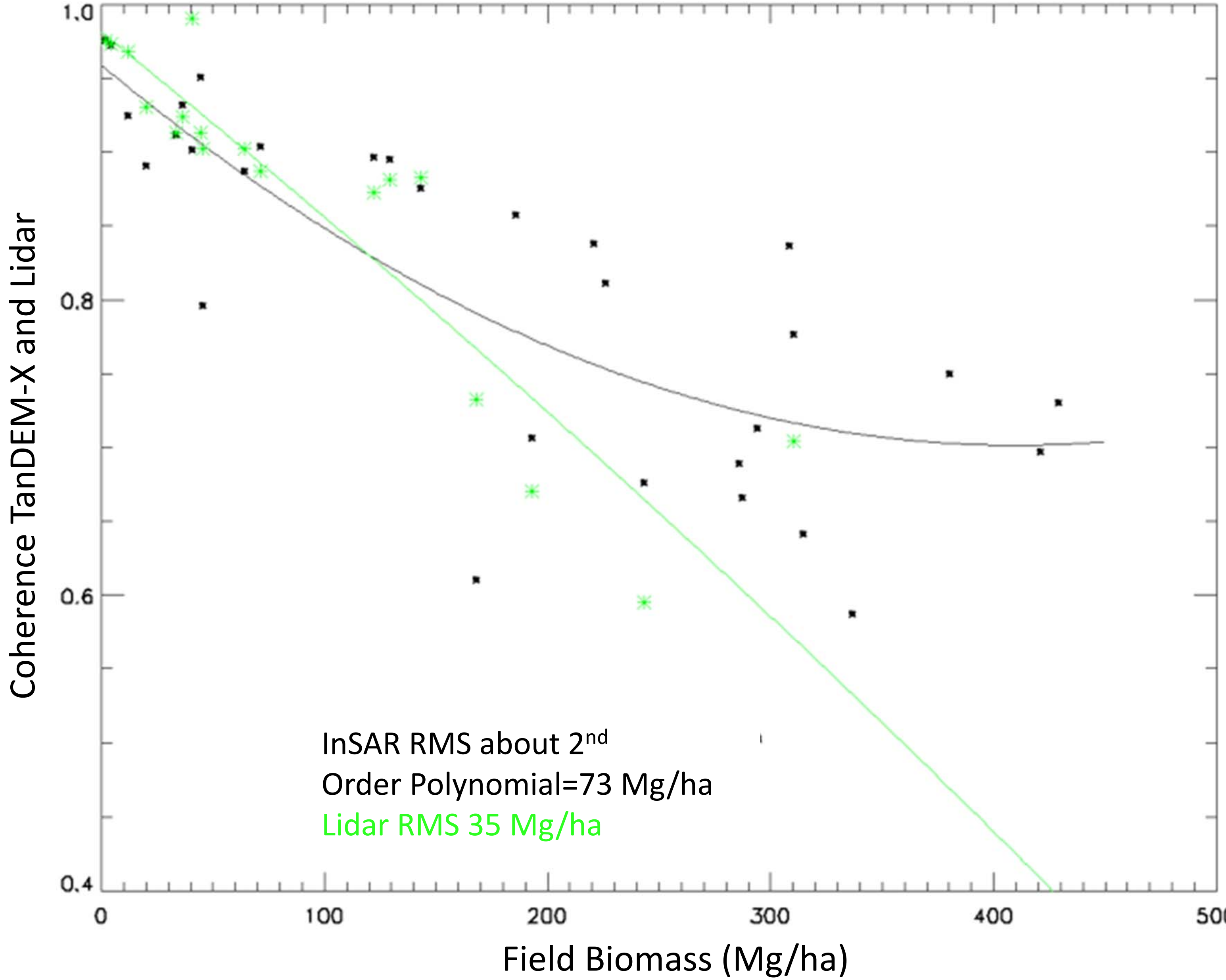
LVIS lidar
Biomass
La Selva

Biomass=a+b*FT(α_z)+c*FT'(α_z)+d*FT''(α_z),
Fourier freq=0.07 cyc/m, and 0.17 cyc/m
Treuhaft et al. 2010 (and in prep)

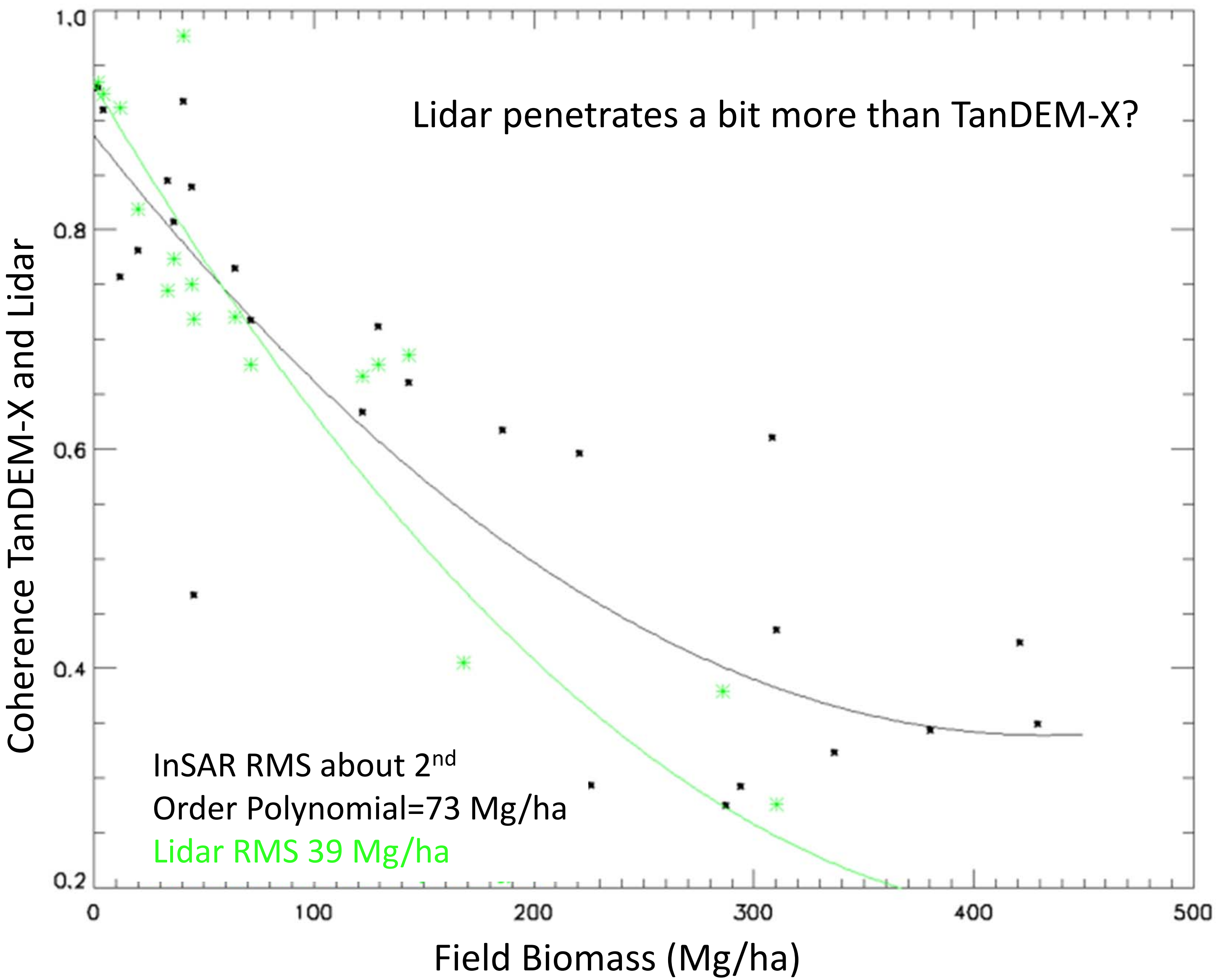
Tapajós


Phase
Coherence
0
20
40
60
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
Interferometric height (1 cycle= 73 m)

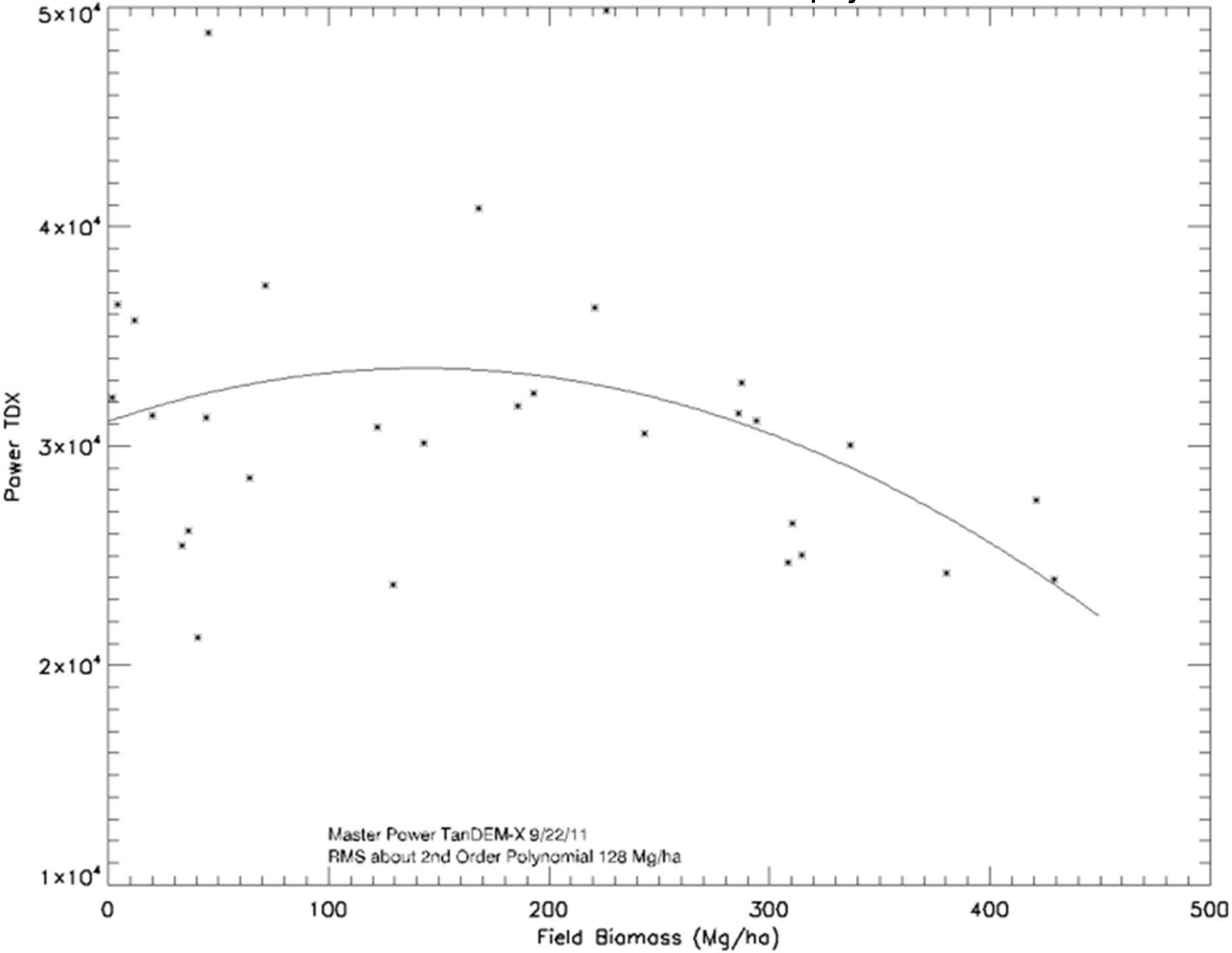
73 m Height Amb X-band Coherence vs Biomass Tapajós



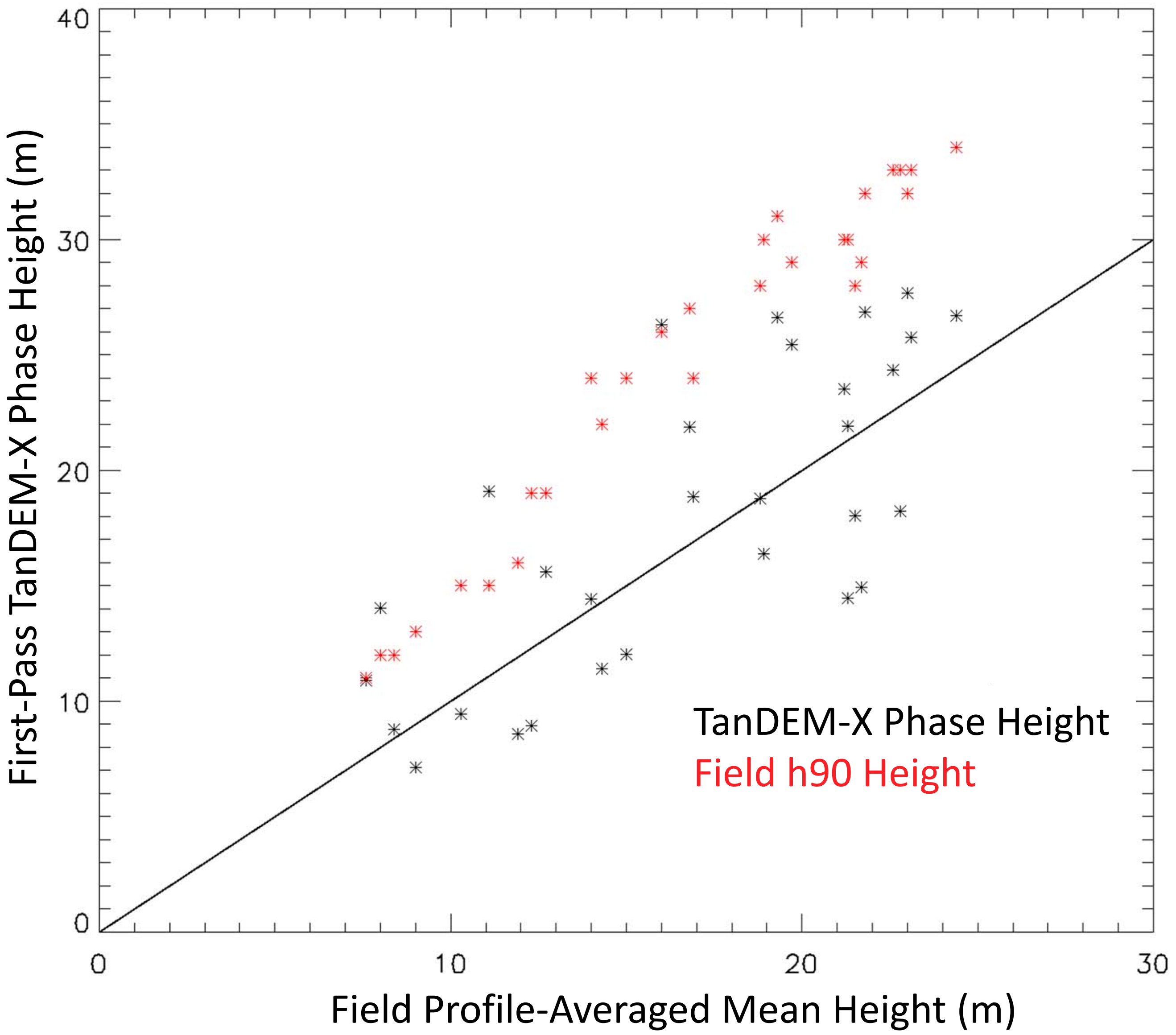
40 m Height Amb InSAR Coherence vs Biomass Tapajós



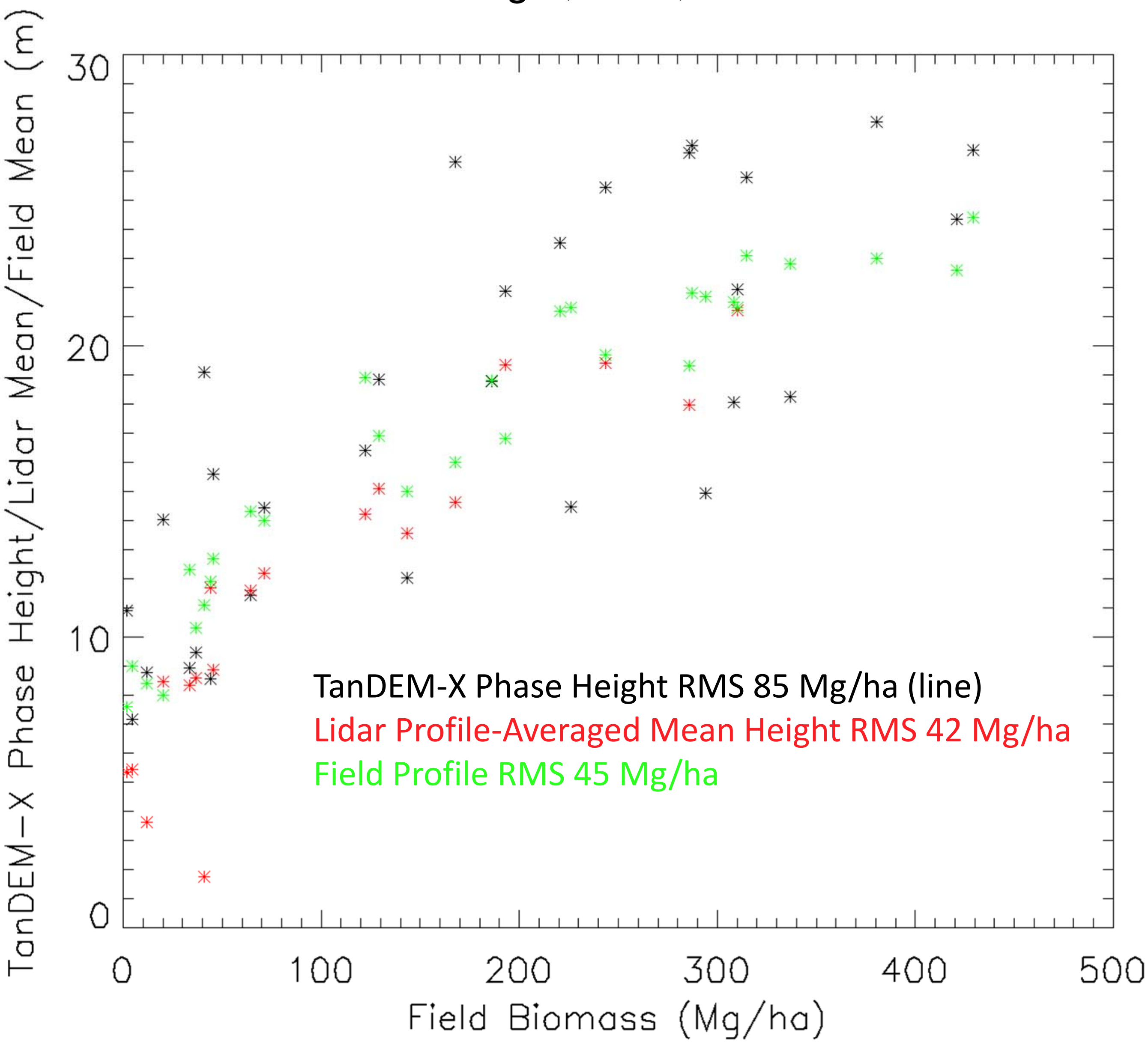
X-band Power vs Biomass Tapajós



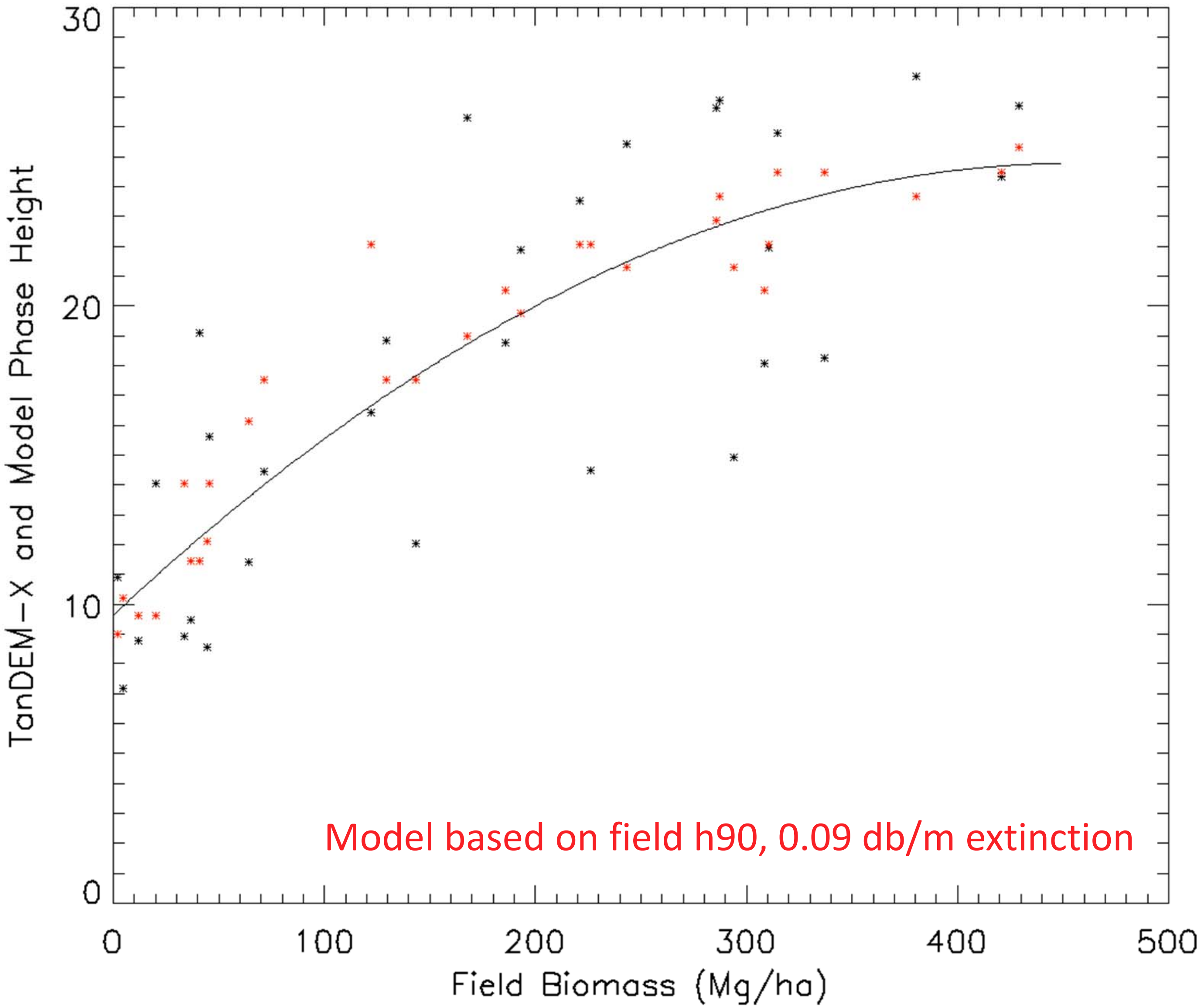
TanDEM-X Phase Height vs Field Mean Height



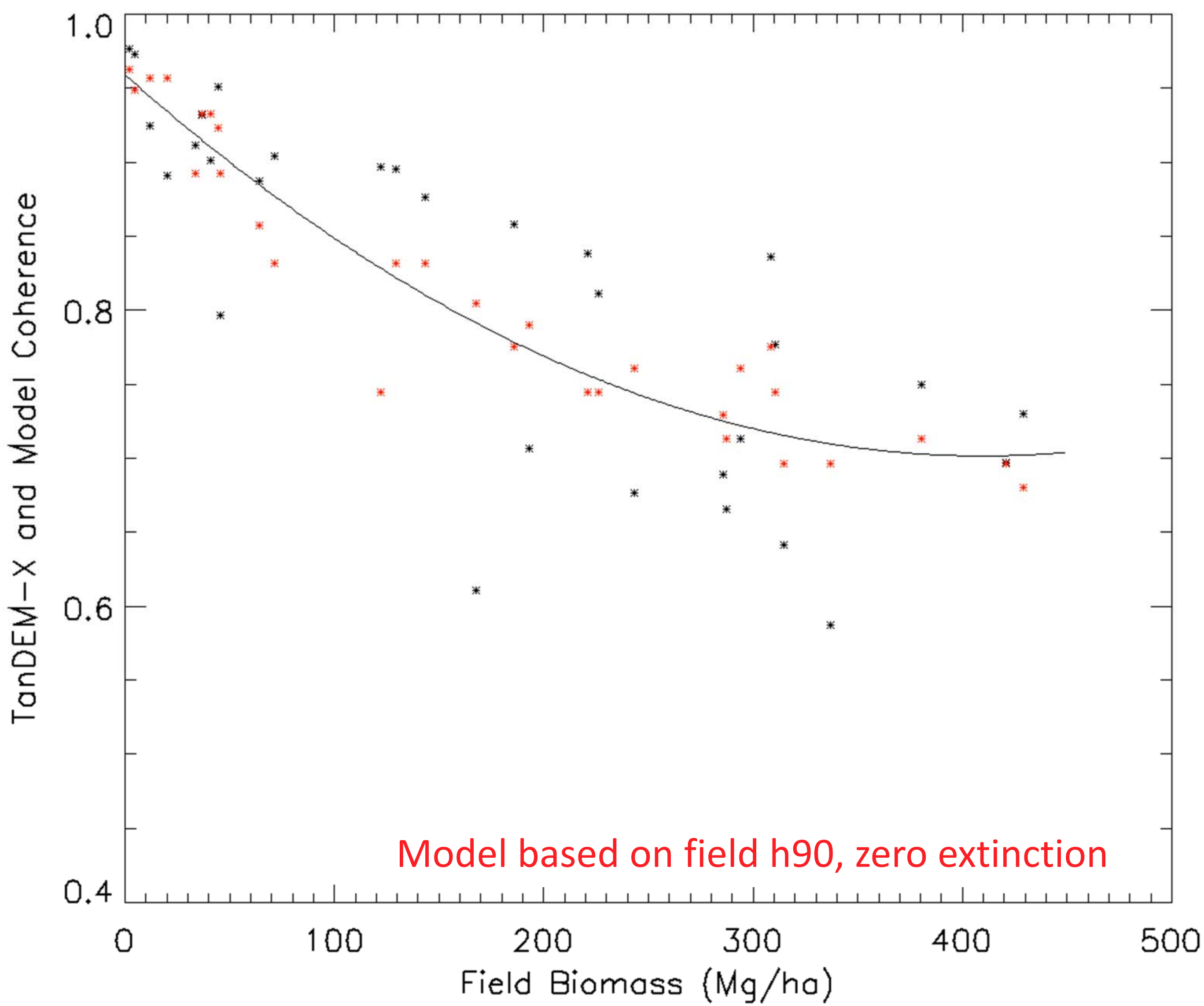
TanDEM-X Phase Height, Lidar, and Field vs Biomass



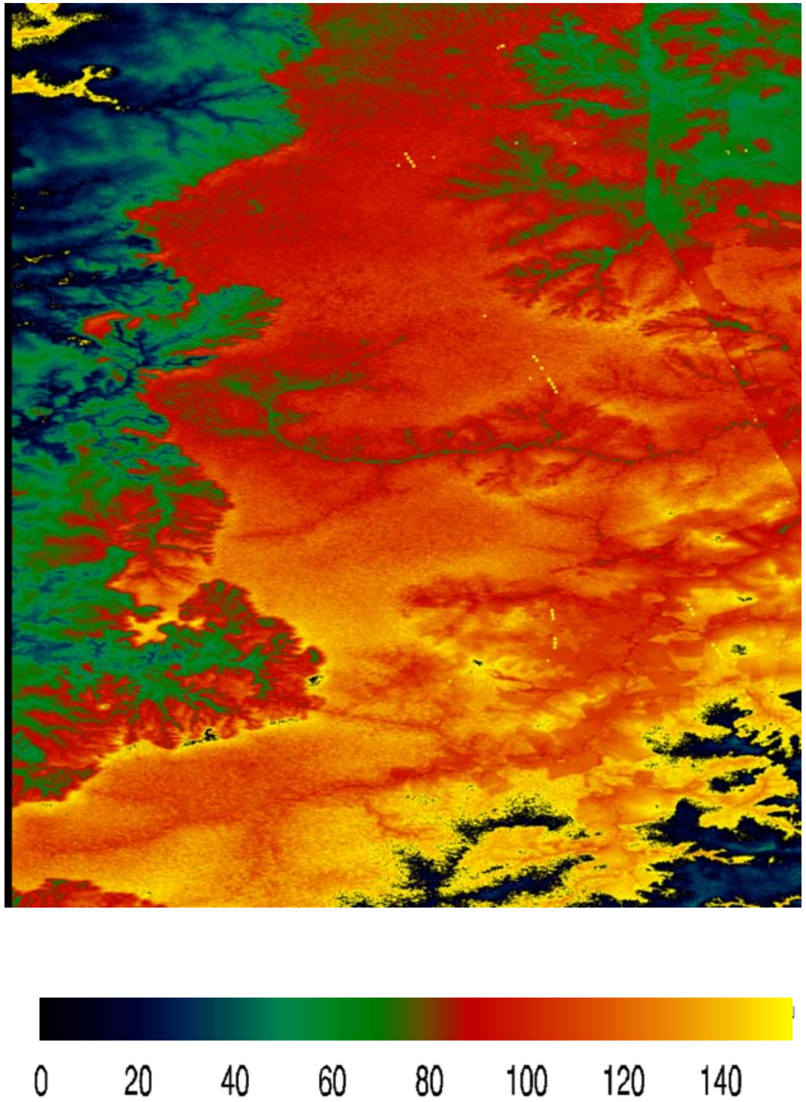
TanDEM-X Phase Height and Model vs Biomass



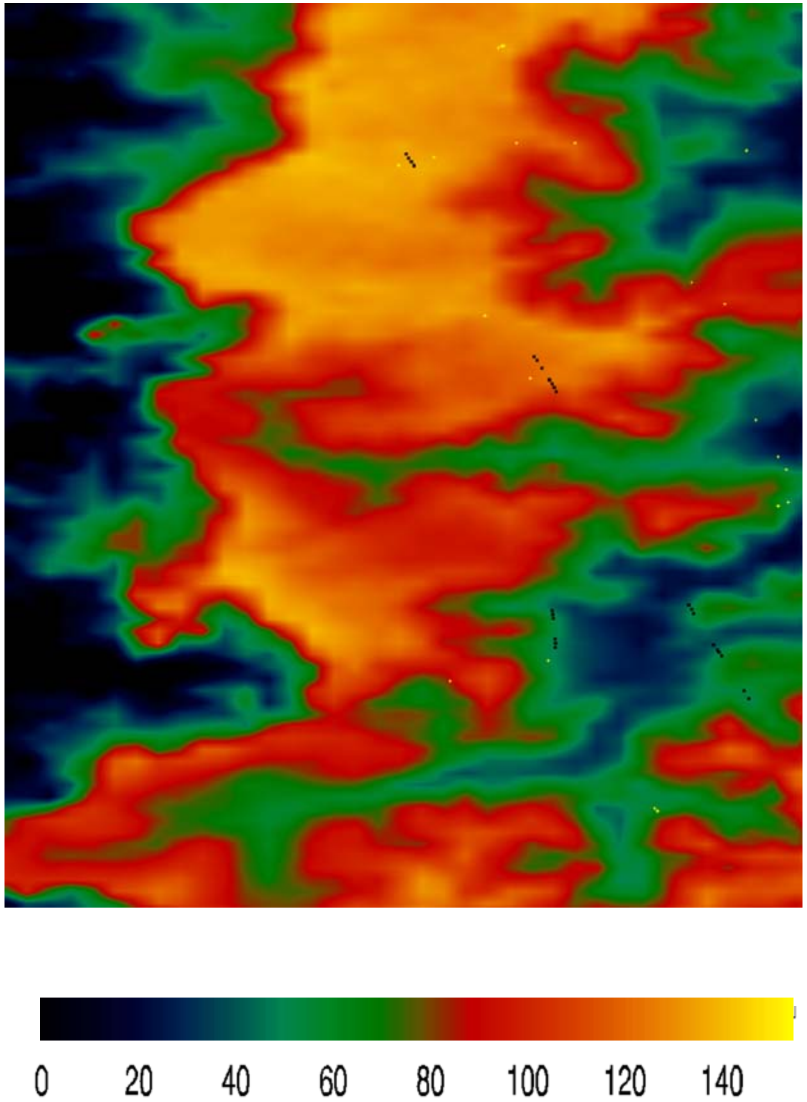
TanDEM-X Coherence and Model vs Biomass



Next: Understand Discrepancy in TanDEM-X and SRTM Topo



Interferometric height (1 cycle= 155 m)



Topographic Height SRTM?

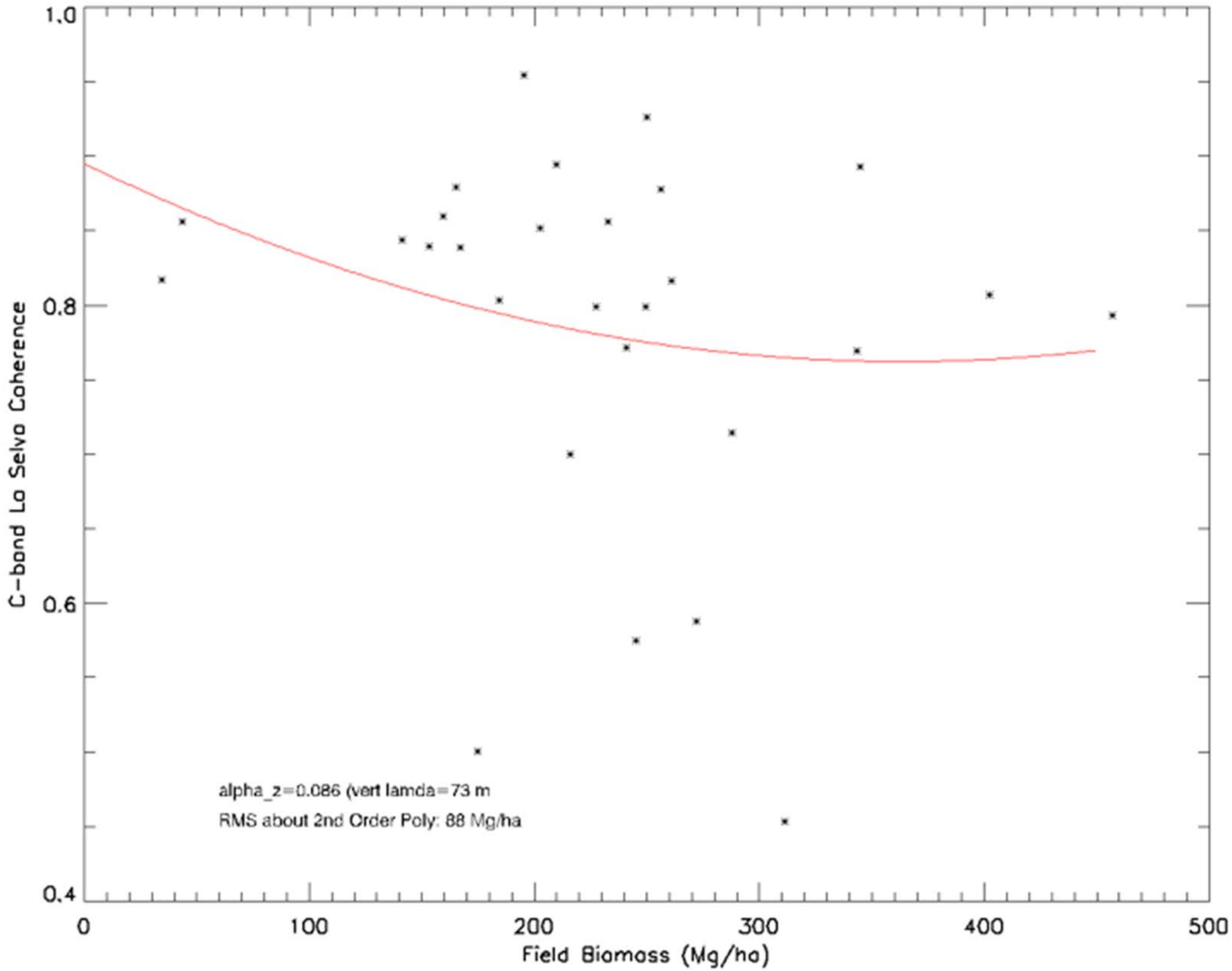
Next

- TanDEM-X structure estimation
  - Understand topo discrepancy
  - Use HH and VV to find phase of ground under canopies
  - Look at shorter baseline signatures for mean canopy height and stddev
  - Account for why TanDEM-X scatter in coherence and phase is greater than lidar
    - Scatter differences >>penetration differences
    - e.g. sidelooking range location shift
  - Phase unwrap

- TanDEM-X biomass estimation
  - Look at preferred Fourier frequencies from lidar alone for biomass est and apply to TanDEM-X short-to-long baselines
  - Compare biomass over 12 thousand .25-ha areas from TanDEM-X and lidar

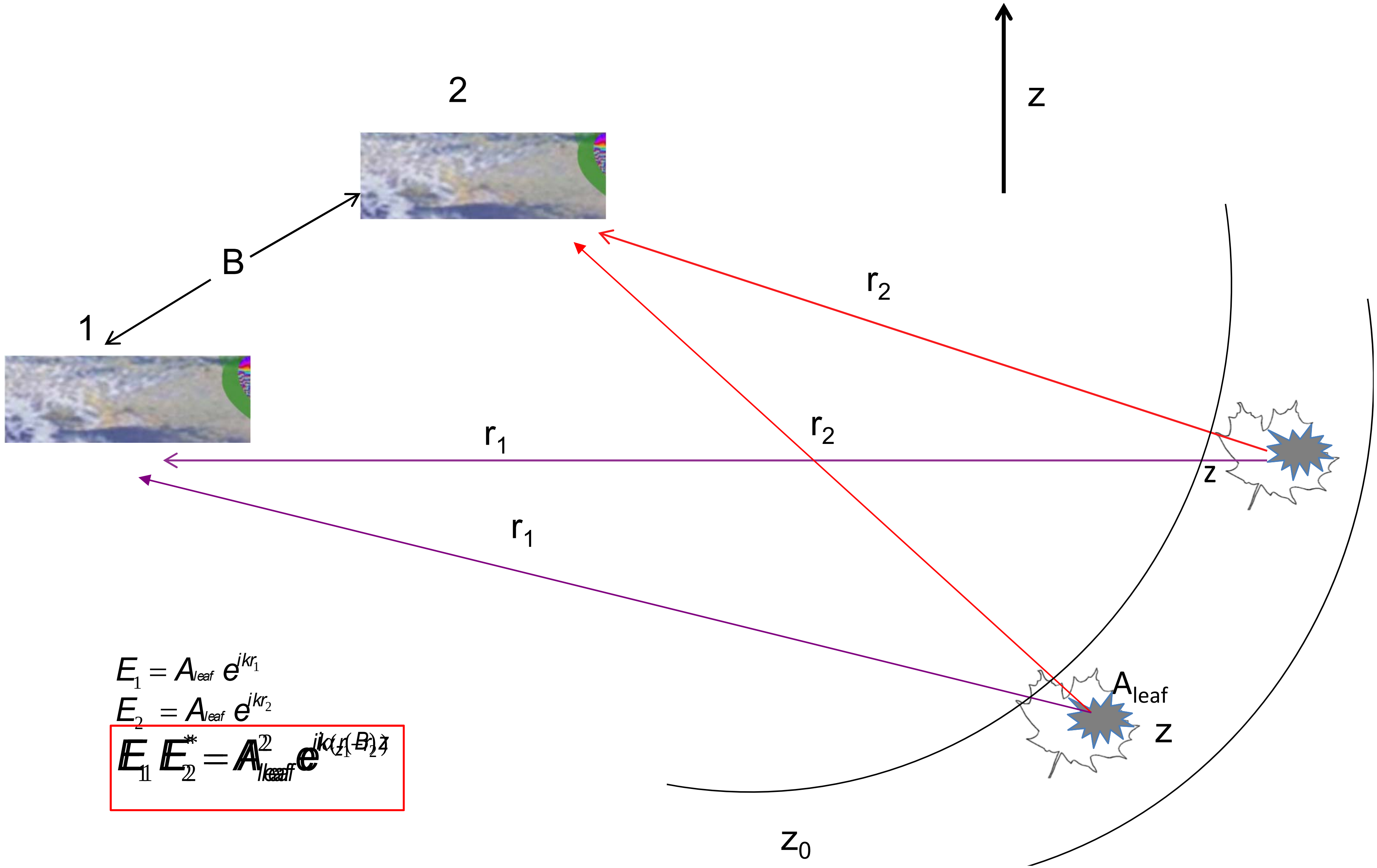
- Perform fieldwork and acquire 50 more sites, also remeasure some from 2010

73 m Height Amb C-band Coherence vs Biomass La Selva



InSAR: Single Scatterer

Interferometeric Phase and Height: SRTM/Topo



$$E_1 = A_{leaf}\, e^{jkr_1}$$

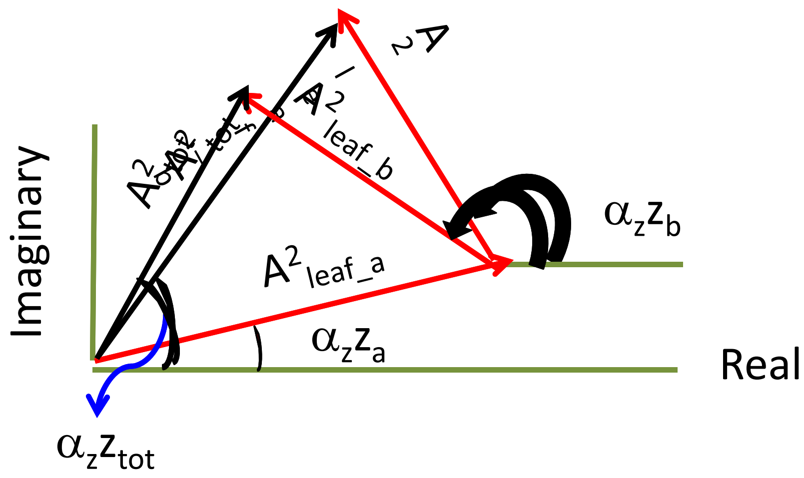
$$E_2 = A_{leaf}\, e^{jkr_2}$$

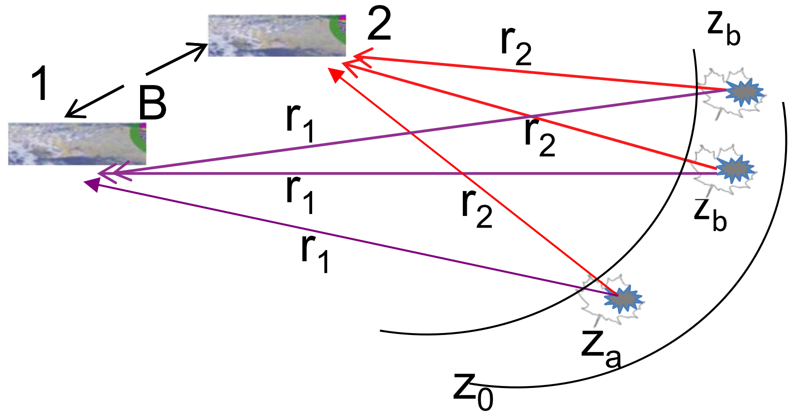
$$E_1 E_2^* = A_{leaf}^2\, e^{jk(r_1 - r_2)}$$

InSAR: Two Vegetation Scatterers

InSAR Phase and Coherence: Terrestrial Ecology

$$E_1E_2^* = \left[A^2_{leaf_a} e^{i\alpha_z(B)z_a} + A^2_{leaf_b} e^{i\alpha_z(B)z_b} \right]$$





Two Conclusions: **The more vertically extended the vegetation**

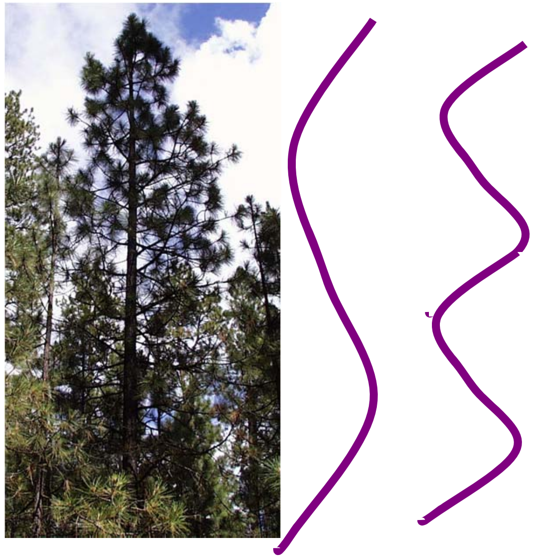
$\alpha_z z_a < \alpha_z z_{tot} < \alpha_z z_b$ **The Higher the phase**

$A^2_{tot} < A^2_{leaf\_a} + A^2_{leaf\_b}$ **The Lower the coherence**

Many Scatterers and The Fourier Transform

The Fourier transform is the strength of the sinusoid at frequency α_z in the profile $A^2(z)$

$$FT(\alpha_z(B)) = \int_0^{\infty} A^2(z)\ e^{j\alpha_z z}\ dz$$



A sufficient number (∞) of Fourier transforms can be used to cook up any signal (profile): inverse Fourier transform

InSAR
Fourier poor

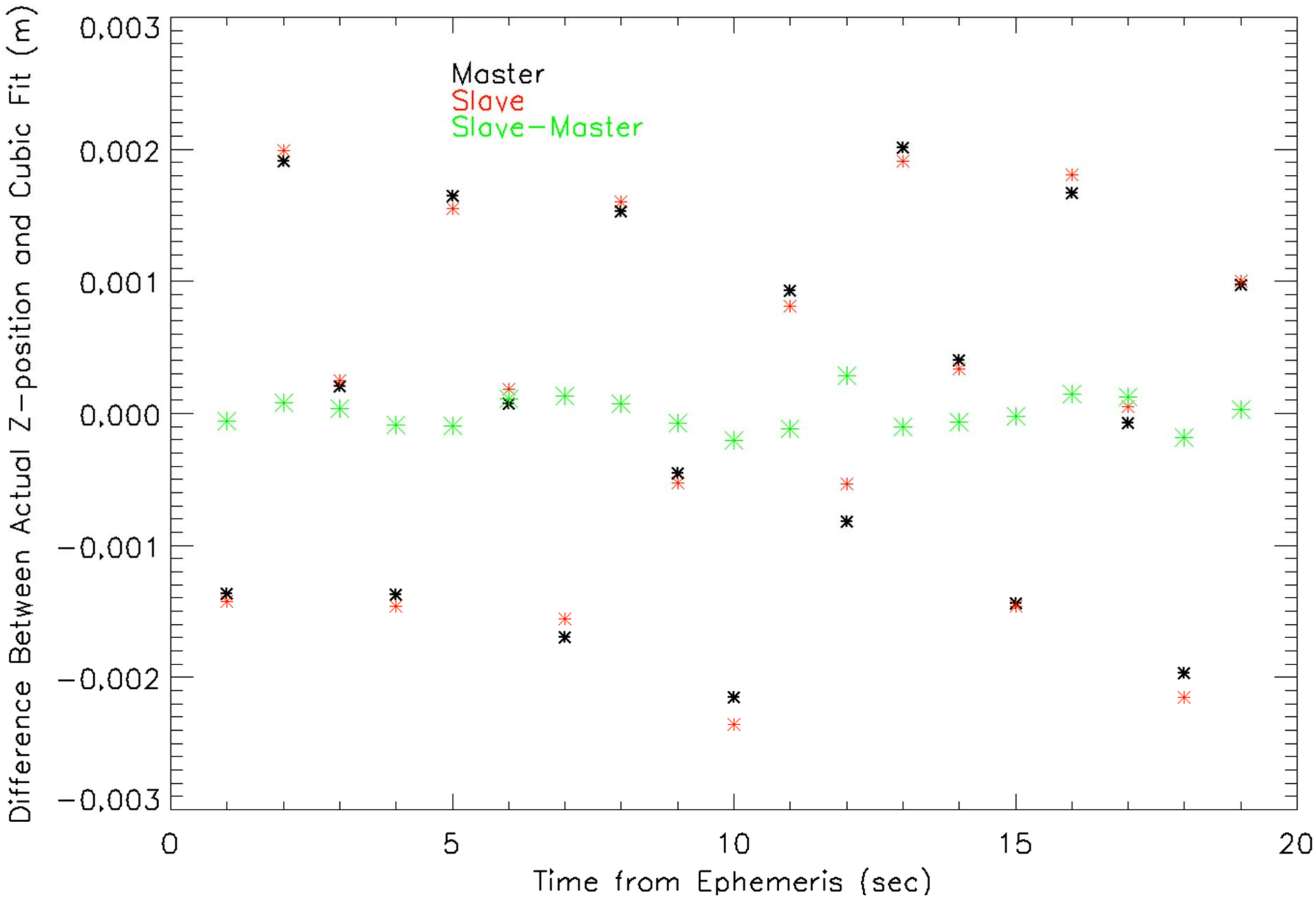
Lidar
Drake et al. 2002
Fourier rich

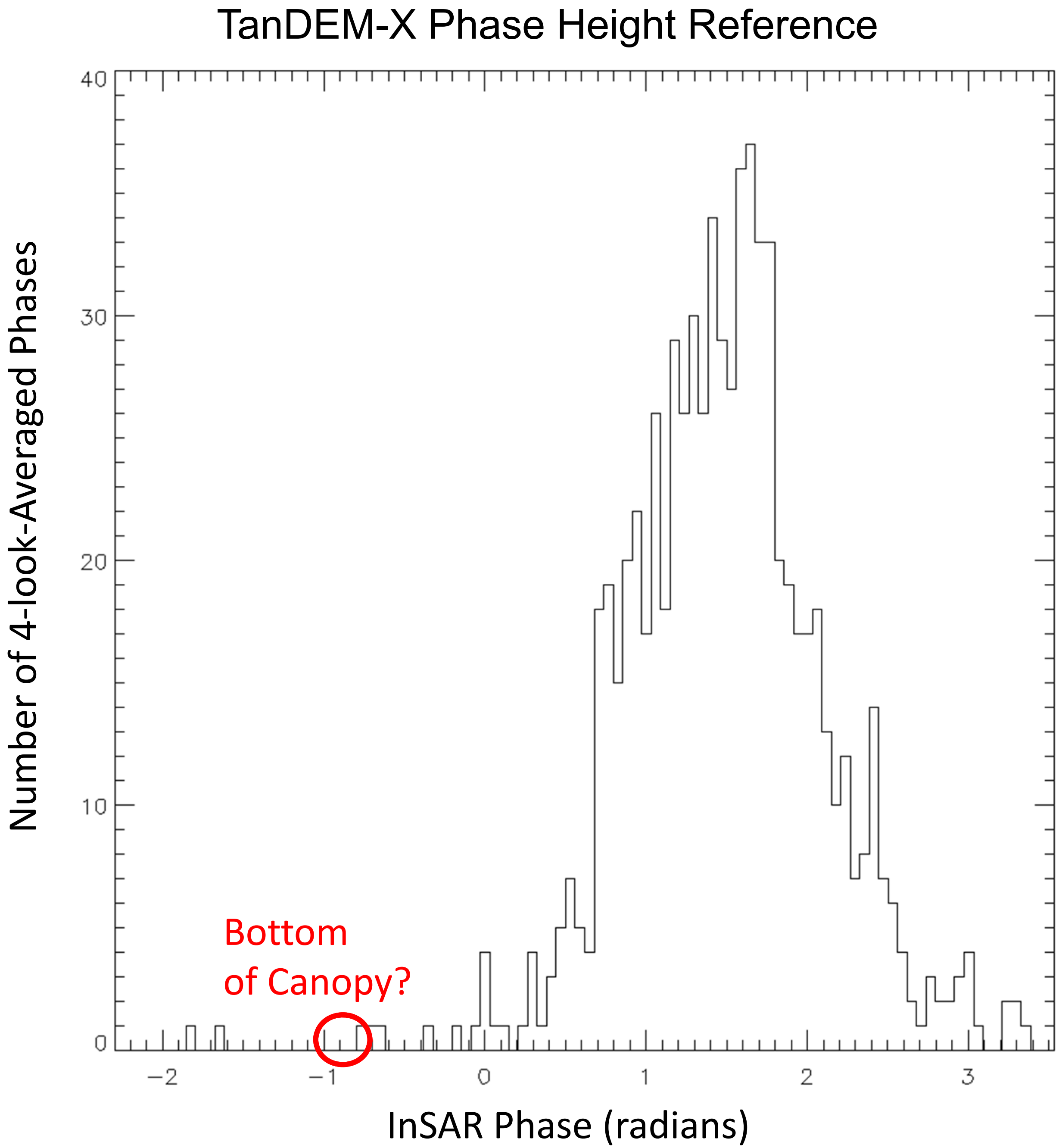
Program for Now

- Look at coherences of TanDEM-X HH InSAR and lidar coherence and phase (phase height)

$$coherence = \frac{\int_0^\infty A^2(z)\ e^{i\alpha_z z}\ dz}{\int_0^\infty A^2(z)\ dz}$$

Next: Understand Differences in TanDEM-X and SRTM Topo: Residual Z-spacecraft coordinate trends?




TanDEM-X Phase Height Reference
40
30
20
10
0
−2
−1
0
1
2
3
Number of 4-look-Averaged Phases
InSAR Phase (radians)
Bottom
of Canopy?

Fourier and Biomass Dynamics

InSAR is a Fourier transform

Fourier transforming lidar over its broad range of frequencies may inform InSAR global monitoring strategies

Modeling Opportunity: The “small push” response of a system in equilibrium is sinusoidal

The frequency of oscillation depends on the forces that maintain equilib

The size of the oscillation sheds light on the force (disturbance)