Tropical-Forest Calibration Requirements for Interferometric SAR by Comparison to Lidar in the Frequency Domain

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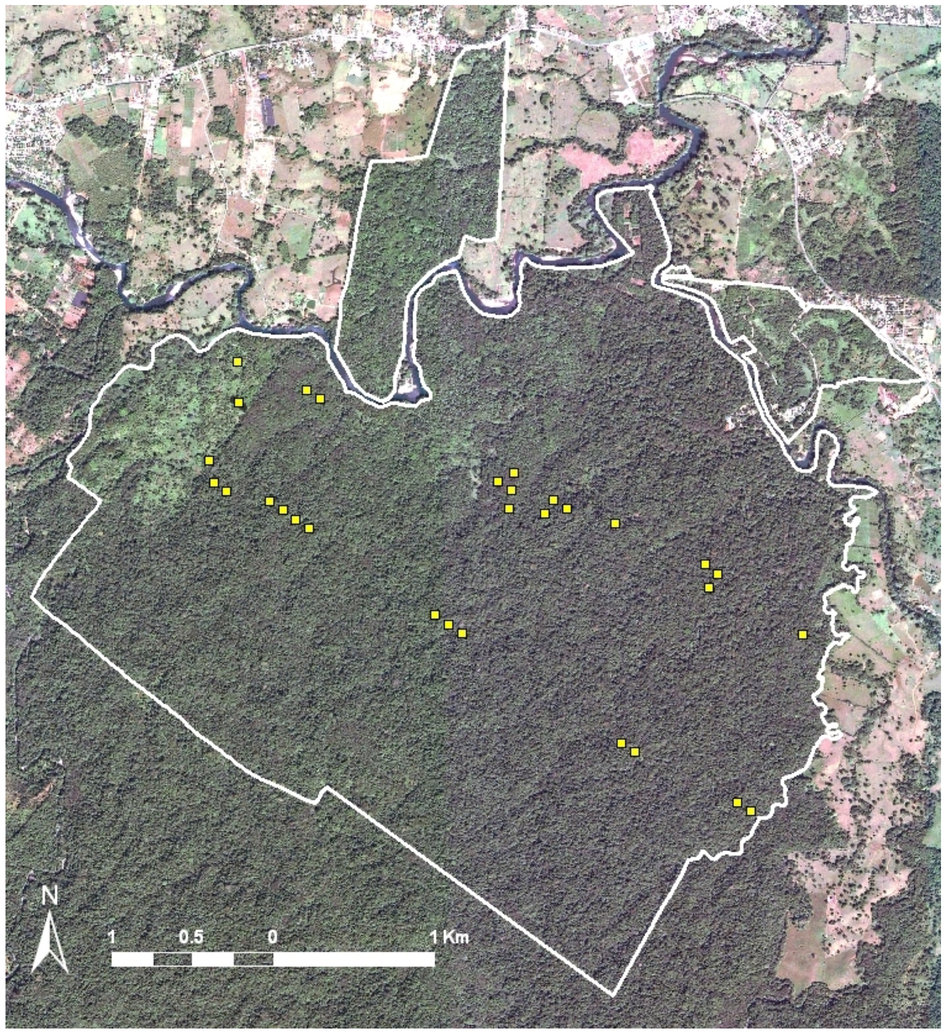
Calibration Requirements for Interferometric SAR by Comparison to Lidar in the Frequency Domain

- Lidar and InSAR data over tropical forests of Costa Rica
  the equivalence of InSAR and lidar for structure
- Biomass performance from lidar/InSAR heights
  at high trop-for biomass, both lidar and InSAR saturate using height
- Beyond Height: Improving lidar and InSAR biomass estimation
  (Fourier) transform lidar→InSAR to determine optimal baselines
  - The low-spatial-frequency nature of heights (HOME, mean, total)
  - Using higher Fourier spatial frequencies (lidar and InSAR)
- How coherence and phase noise restrict biomass estimation performance
  Phase and coherence calibration requirements: How do we make
  InSAR biomass estimates as accurate as those of lidar?

InSAR and Lidar data over tropical forests of Costa Rica

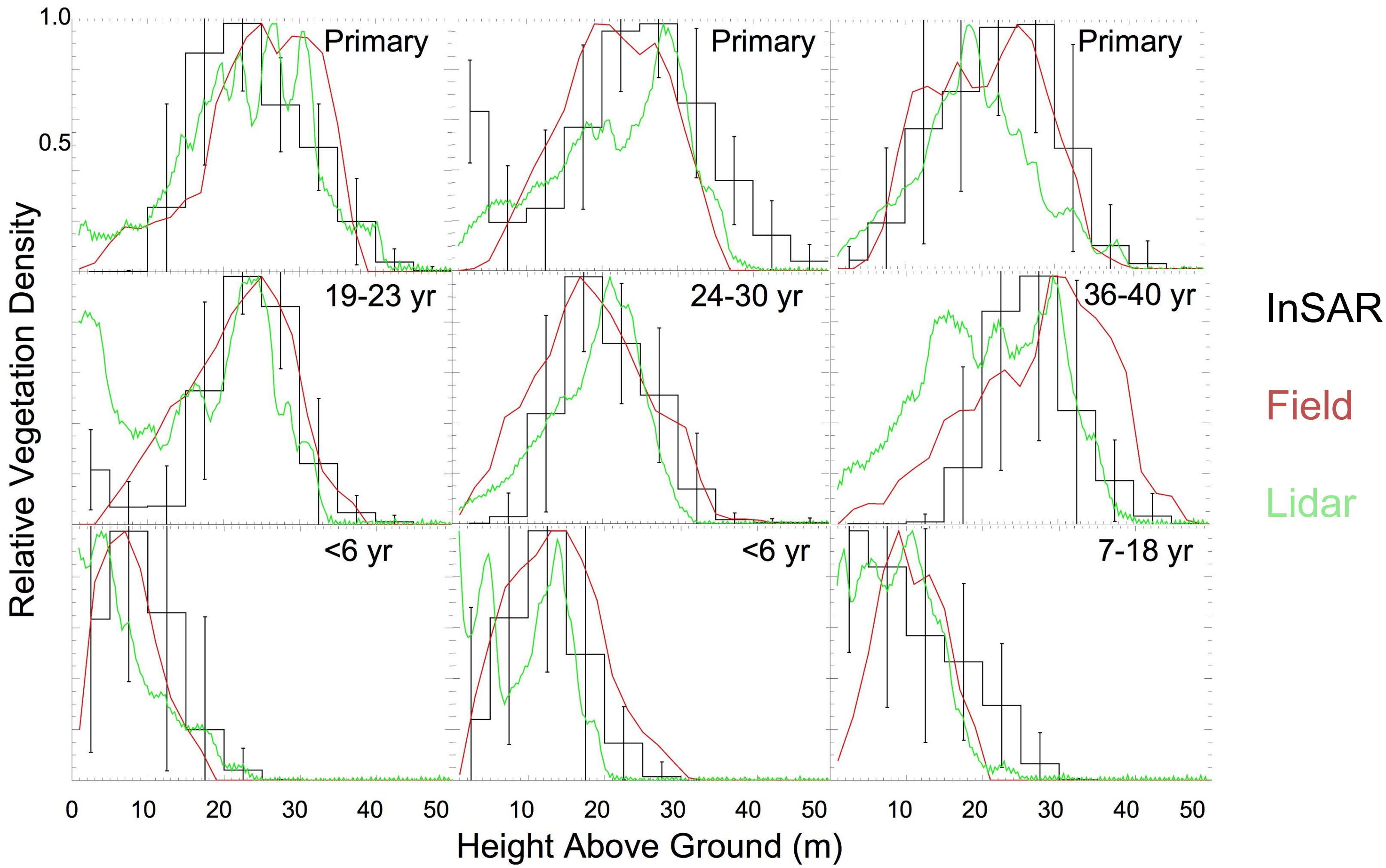
La Selva: InSAR (AirSAR) 2004, lidar (LVIS*) 2005, field 2006



*J. B. Blair, M. A. Hofton, and D. L. Rabine, Processing of NASA LVIS elevation and canopy (LGE, LCE and LGW) data products, version 1.01, http://lvis.gsfc.nasa.gov, (2006).

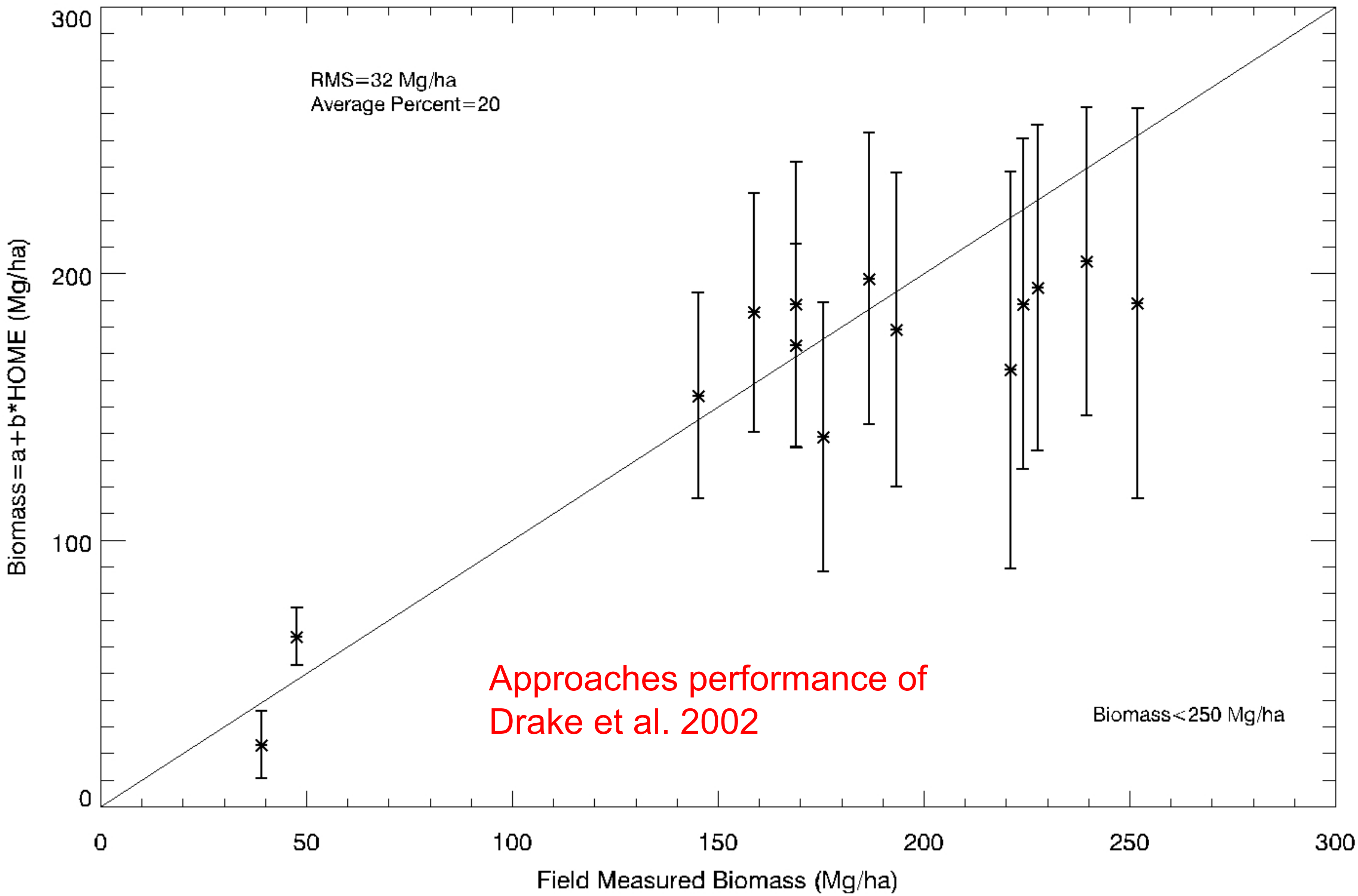
InSAR and Lidar data over tropical forests of Costa Rica

The equivalence of lidar and InSAR for structure

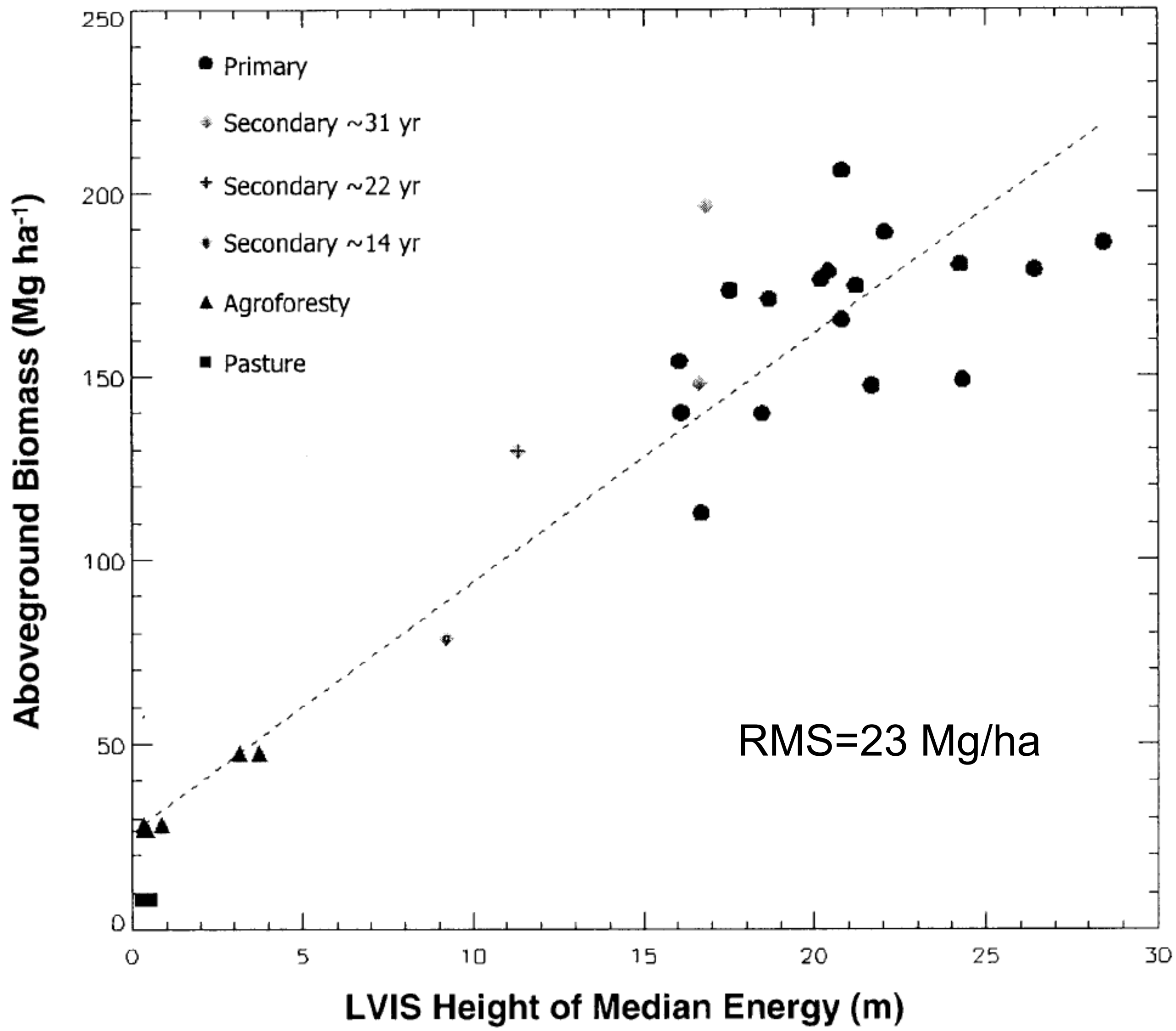


Treuhaft, Chapman, dos Santos, Gonçalves, Dutra, Graça, Drake, JGR-Atmospheres (in press)

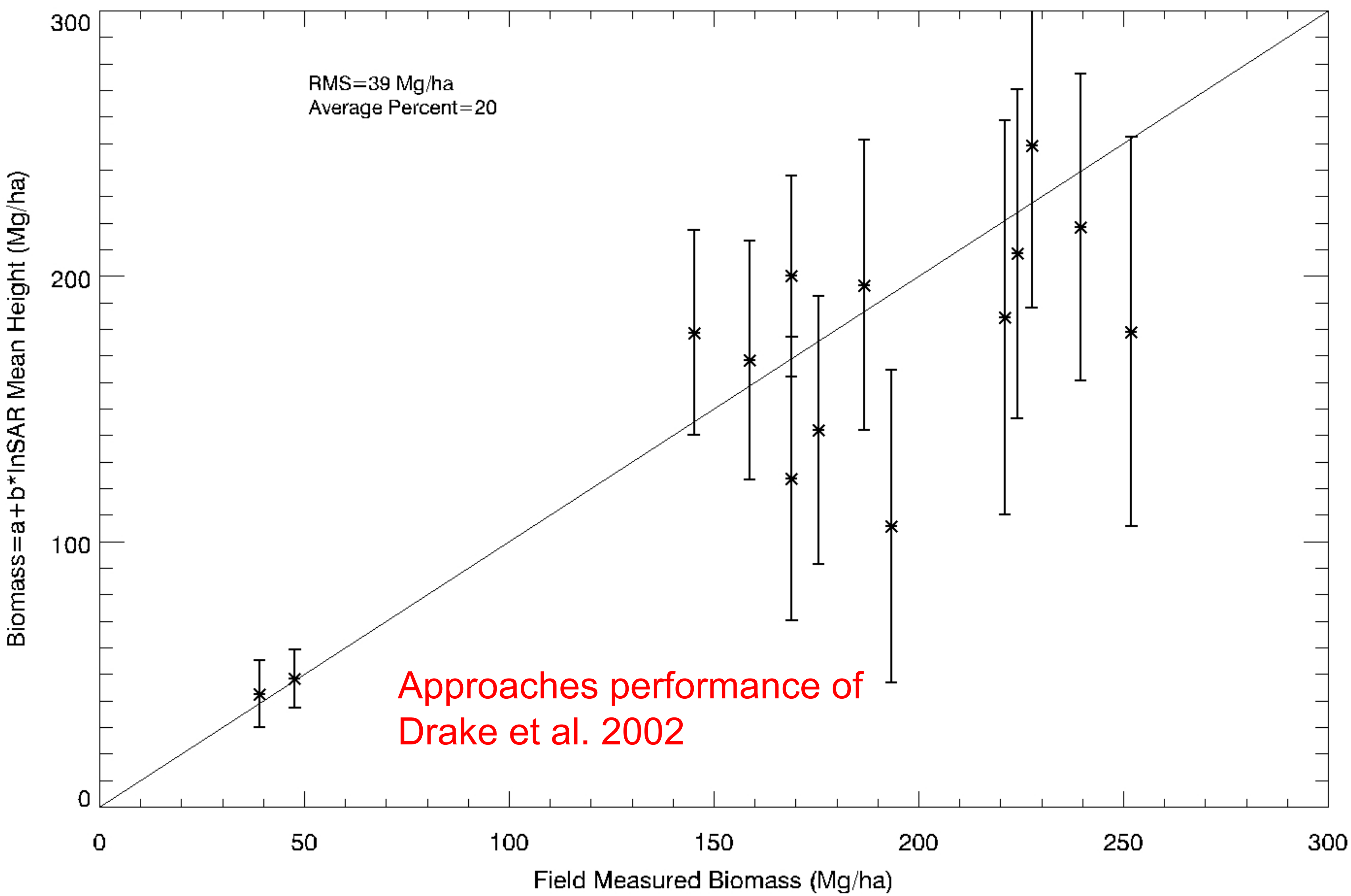
Biomass performance from **Lidar** height (HOME):
Low Biomass (<250 Mg/ha, less one outlier)



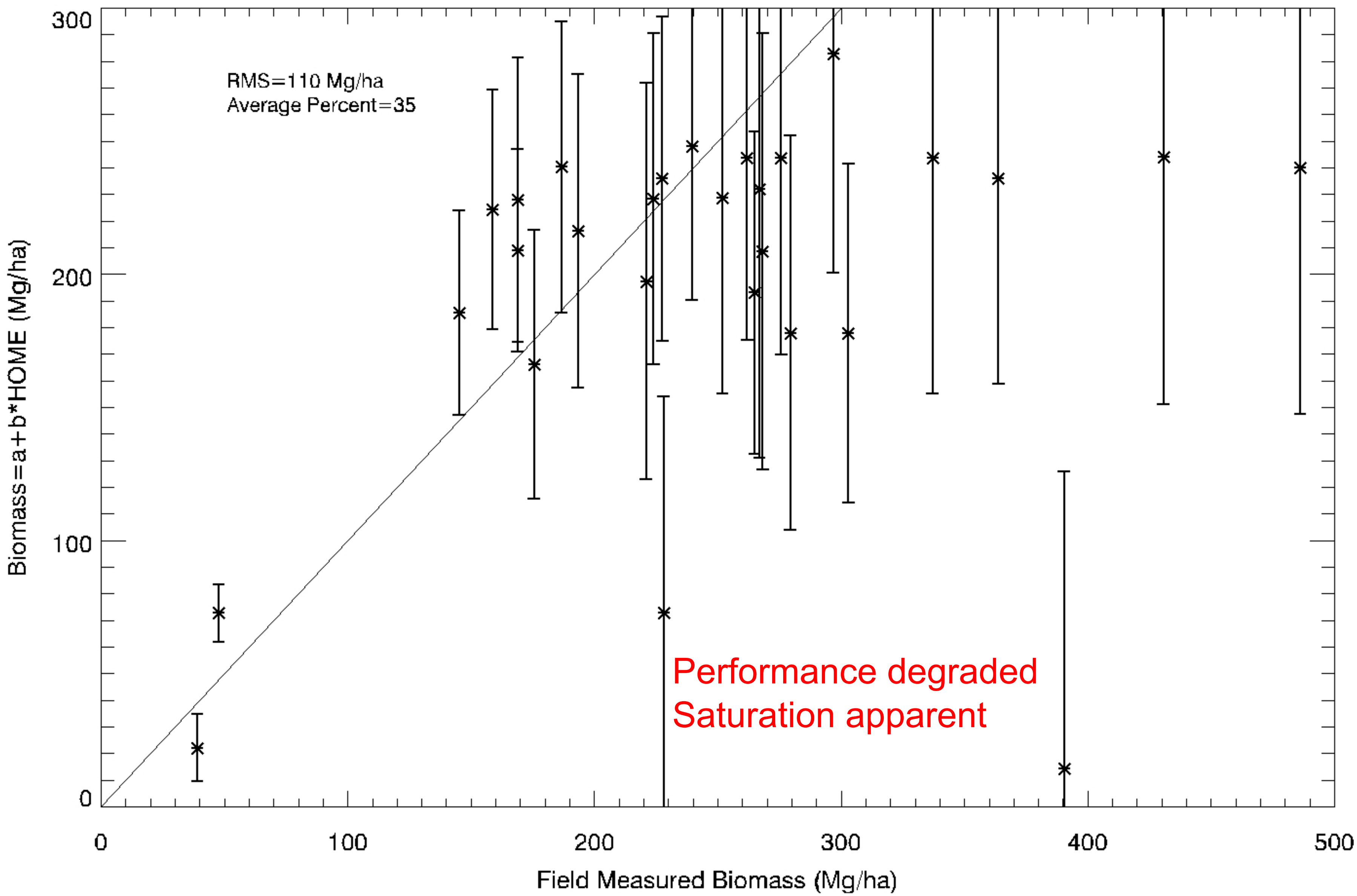
Biomass performance from **Lidar** Height of Median Energy (HOME): Low Biomass (Drake et al. 2002)



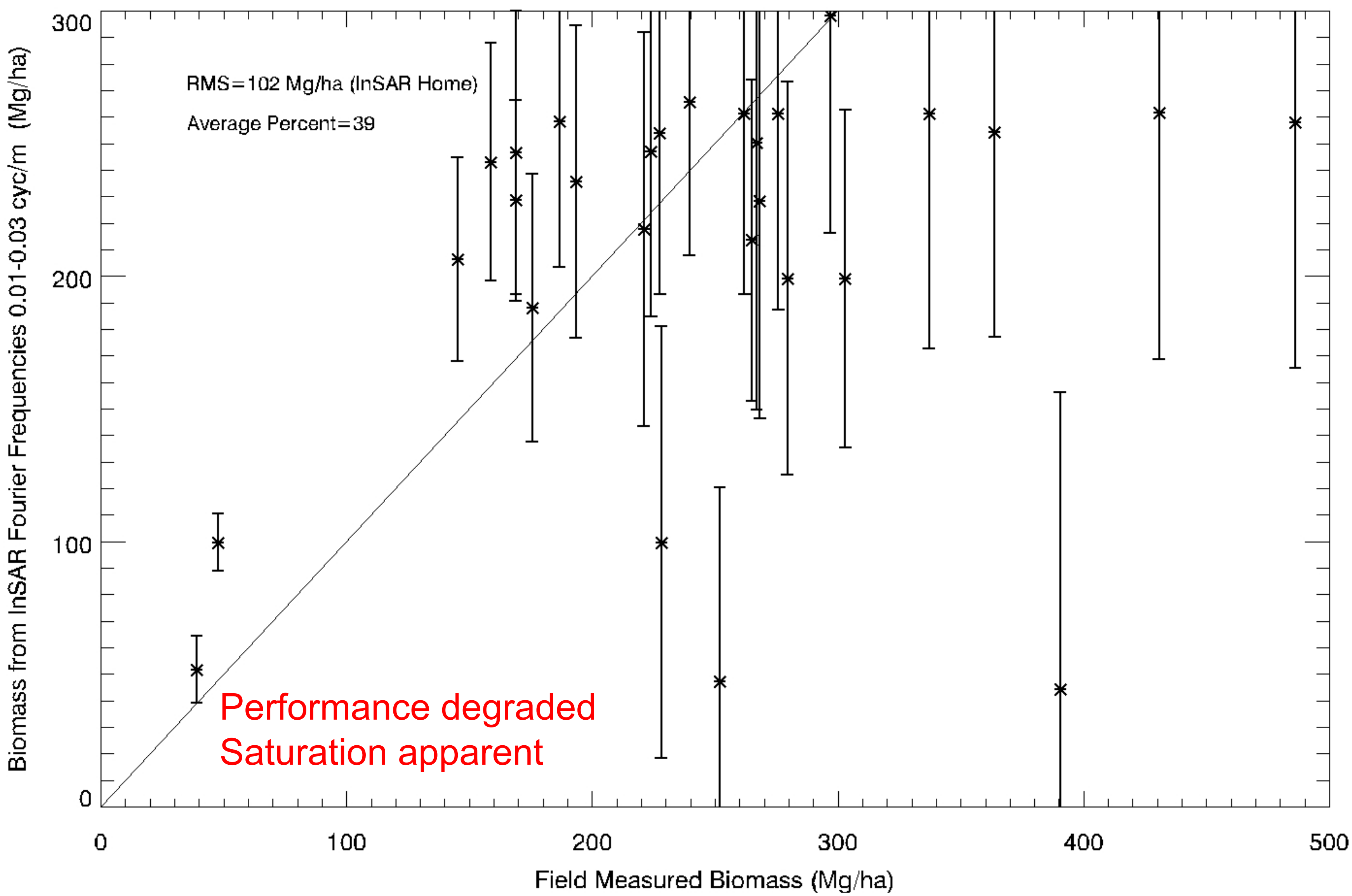
Biomass performance from C-band Multibaseline InSAR Mean Height: Low Biomass (less one outlier)



Biomass performance from **Lidar** HOME (Mean):
All Biomasses<500 Mg/ha



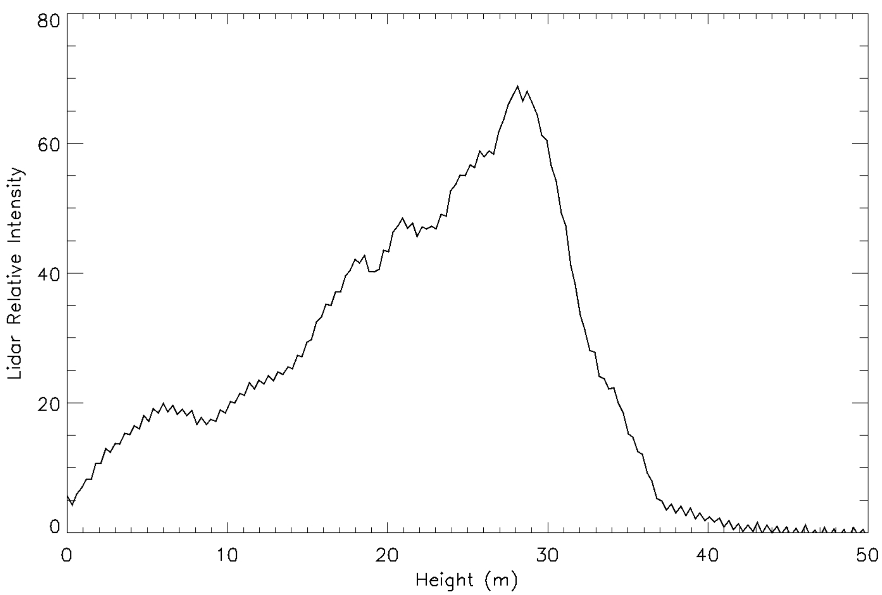
Biomass performance from **InSAR** HOME (Mean):
All Biomasses<500 Mg/ha

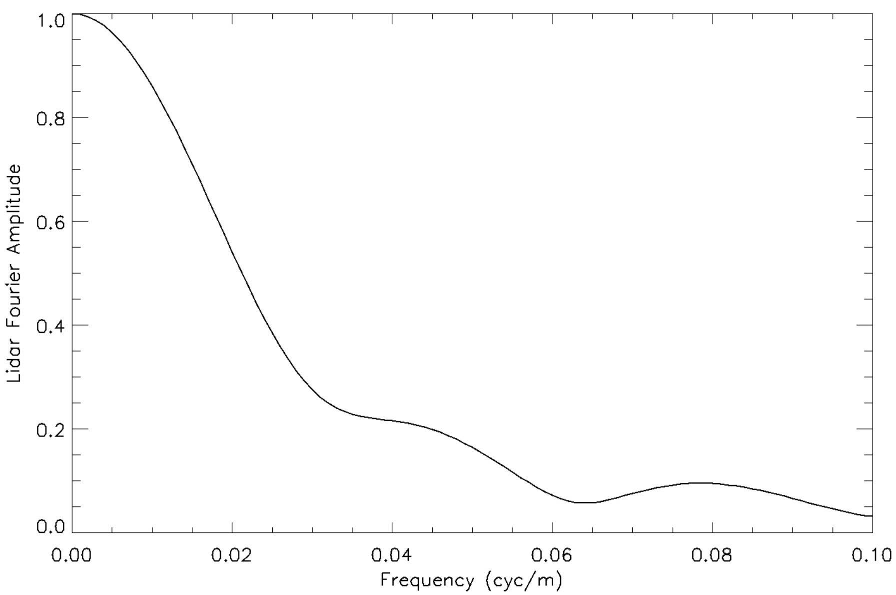


The Low-Spatial-Frequency Nature of Heights

Fourier Transform of Lidar Waveform

$$\gamma(\omega) \equiv \frac{1}{2\pi} \int waveform(z) \;\; e^{i\omega z} \;\; dz$$





$$\gamma_{InSAR}(\kappa_z(\vec{B})) \equiv \frac{1}{2\pi} \int < f^2(z) > Att(z) \;\; e^{i\kappa_z z} \;\; dz$$

The Low-Spatial-Frequency Nature of Heights: Moments and Frequencies

Fourier Transform of Lidar Waveform

$$\frac{d\gamma(\omega)}{d\omega} = \frac{i}{2\pi}\int z \;\; waveform(z) \;\; e^{i\omega z} \;\; dz$$

$$\lim\ \omega \to 0\ \ \frac{d\gamma(\omega)}{d\omega} = \frac{i}{2\pi}\int z \;\; waveform(z) \;\; dz = \text{Mean Height} = \text{First Moment}$$

$$\lim\ \omega \to 0\ \ \frac{d^n\gamma(\omega)}{d\omega^n} = \frac{i^n}{2\pi}\int z^n \;\; waveform(z) \;\; dz = Average \;\; z^n$$

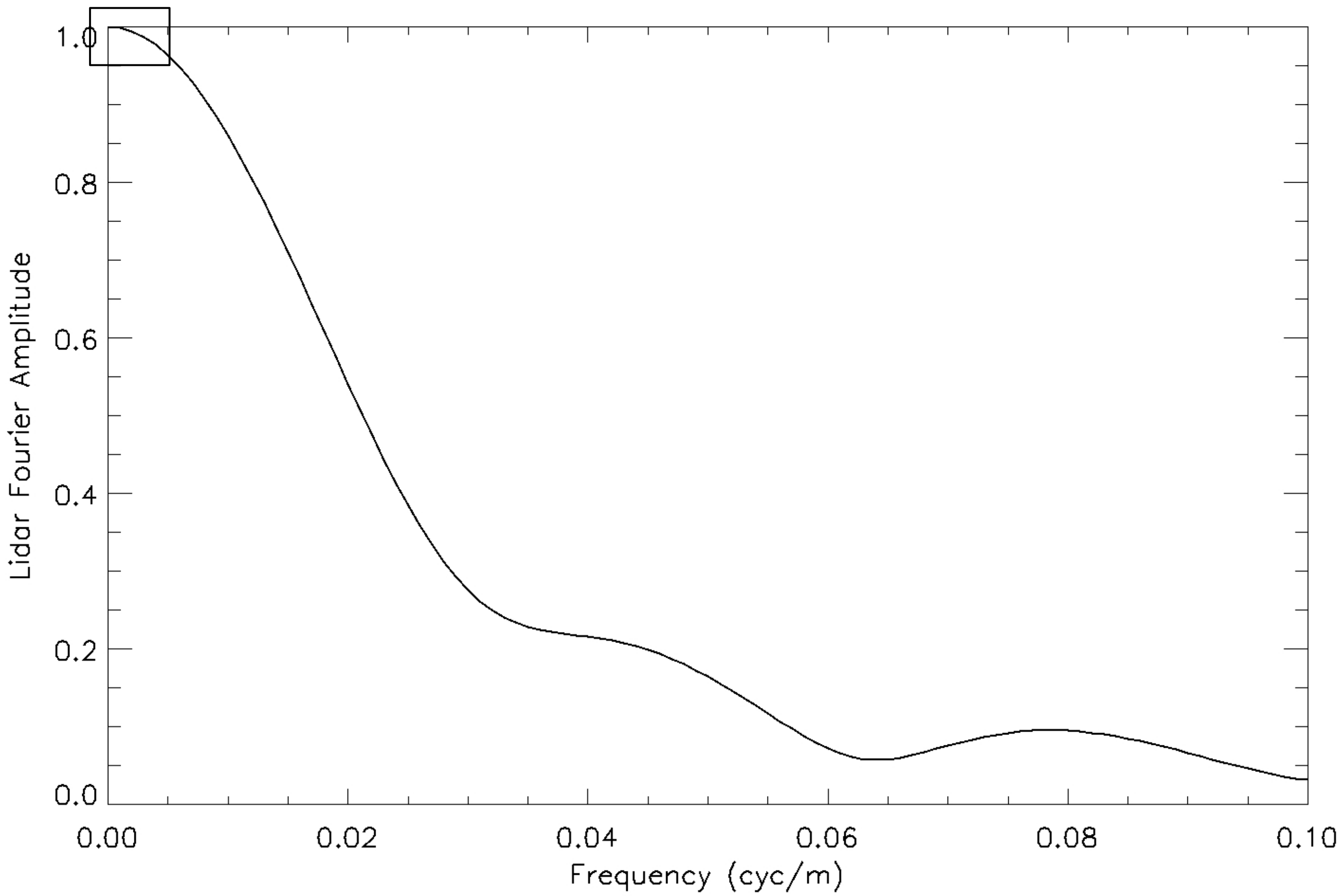
$$= \text{ n}^{\text{th}} \text{ moment}$$

$\Rightarrow$

Mean, standard deviation, total height (~mean +2*standard deviation) All depend on the shape of the Fourier transform near zero (low) frequency

The Low-Spatial-Frequency Nature of Heights: Moments and Frequencies

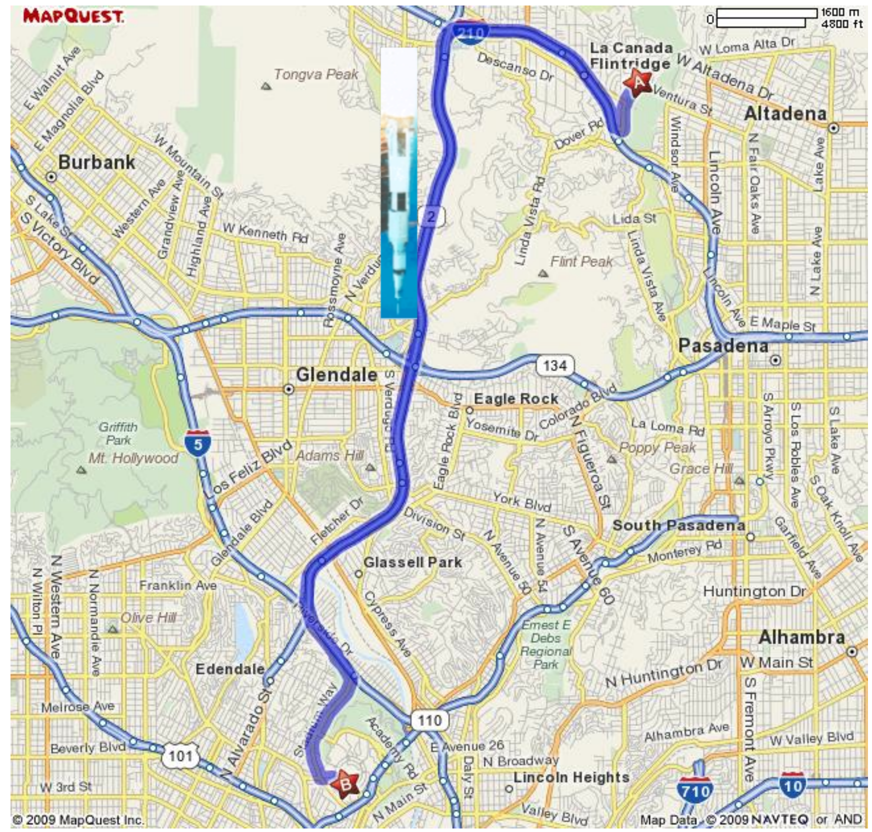
⇒ Mean, standard deviation, total height (~mean +2*standard deviation)
All depend on the shape of the Fourier transform near zero (low) frequency



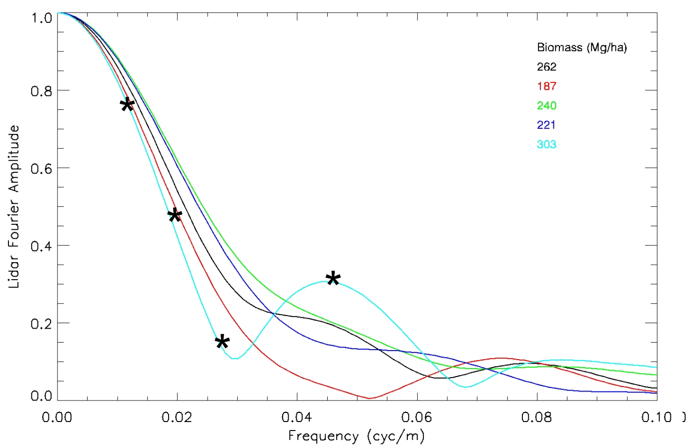
Using HOME, mean height, standard deviation for Biomass Estimation from Lidar or InSAR is…

Like using a Saturn V

to go to a Dodger game



Instead



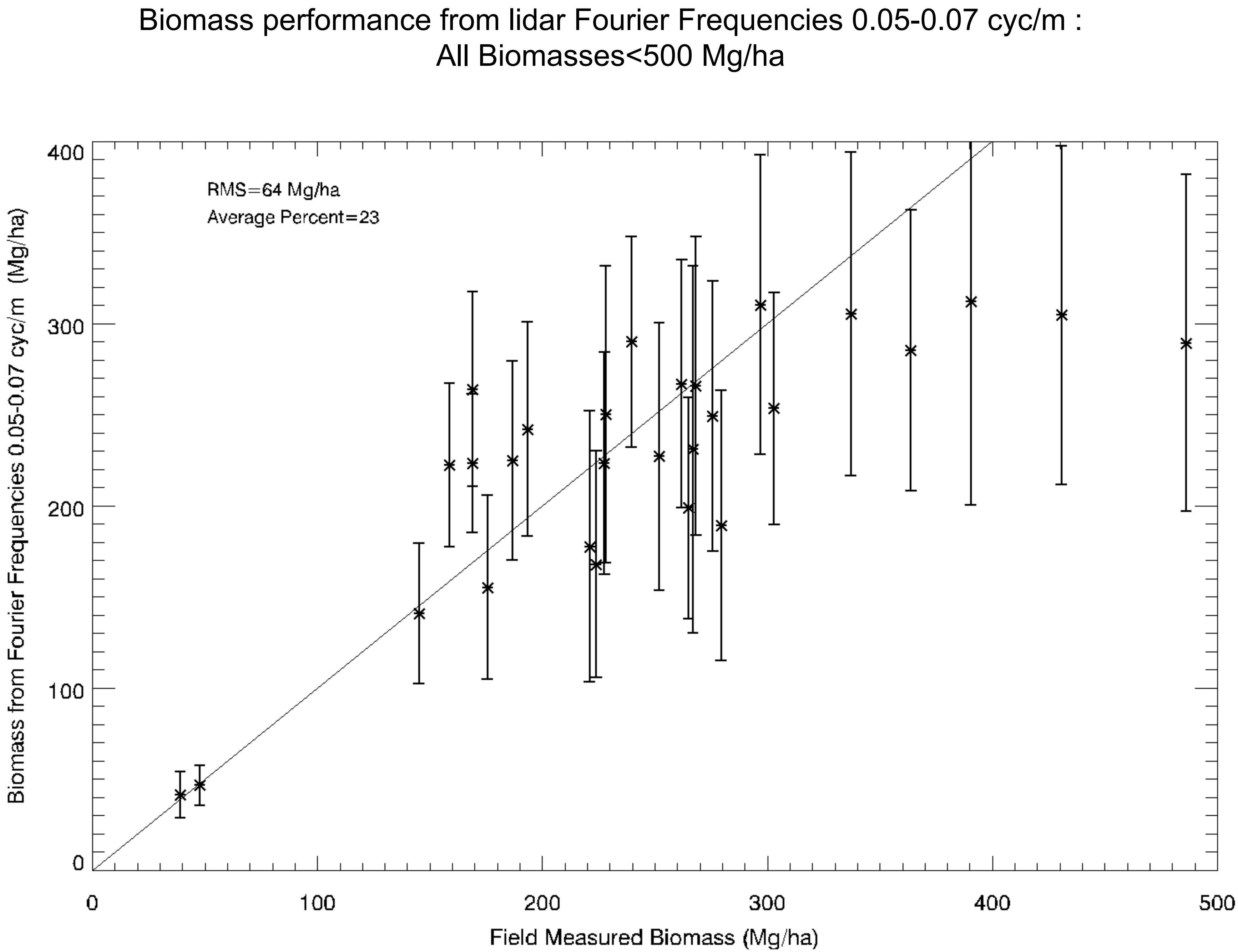
…of HOME/mean Regression
Do Fourier regression and use more of the Lidar/InSAR spectrum

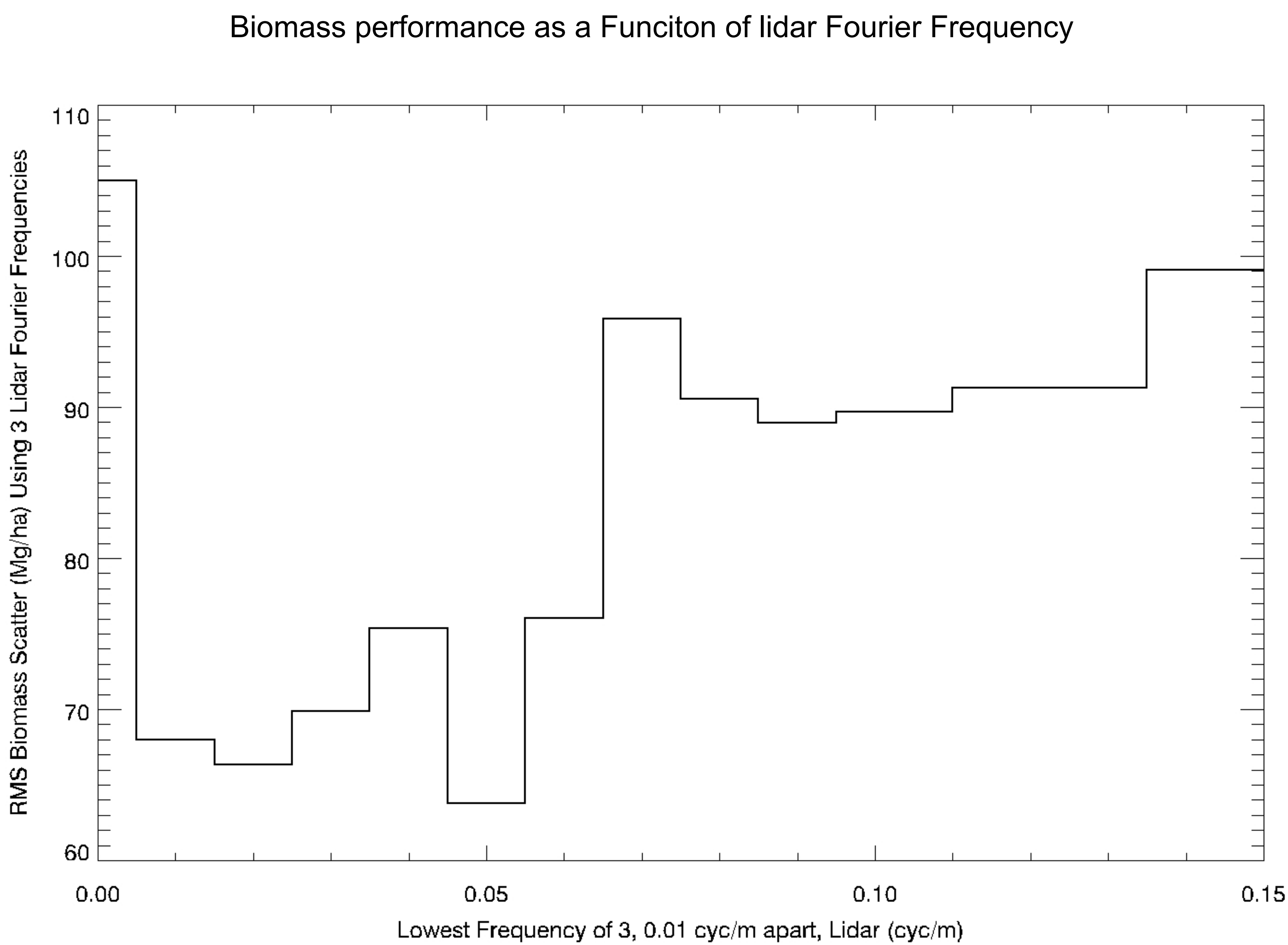
Instead of

$$Biomass = a + b * HOME = a + b * \left.\frac{d\gamma(\omega)}{d\omega}\right|_{\omega=0}$$

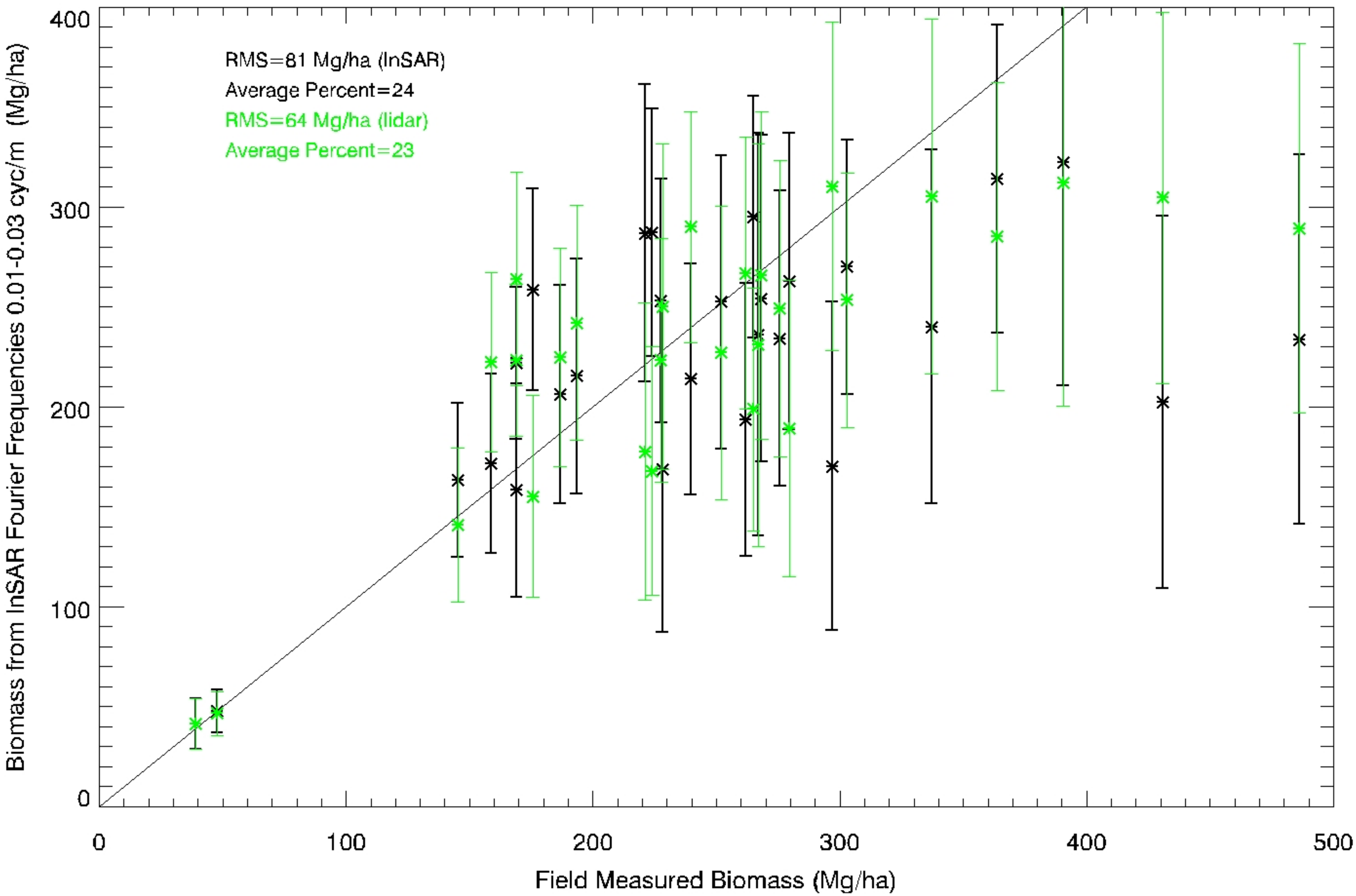
Fourier Regression:

$$Biomass = a_0 + \sum_{j=1}^{n} a_j \; real\left[\gamma(\omega_j)\right] + b_j \; imag\left[\gamma(\omega_j)\right]$$

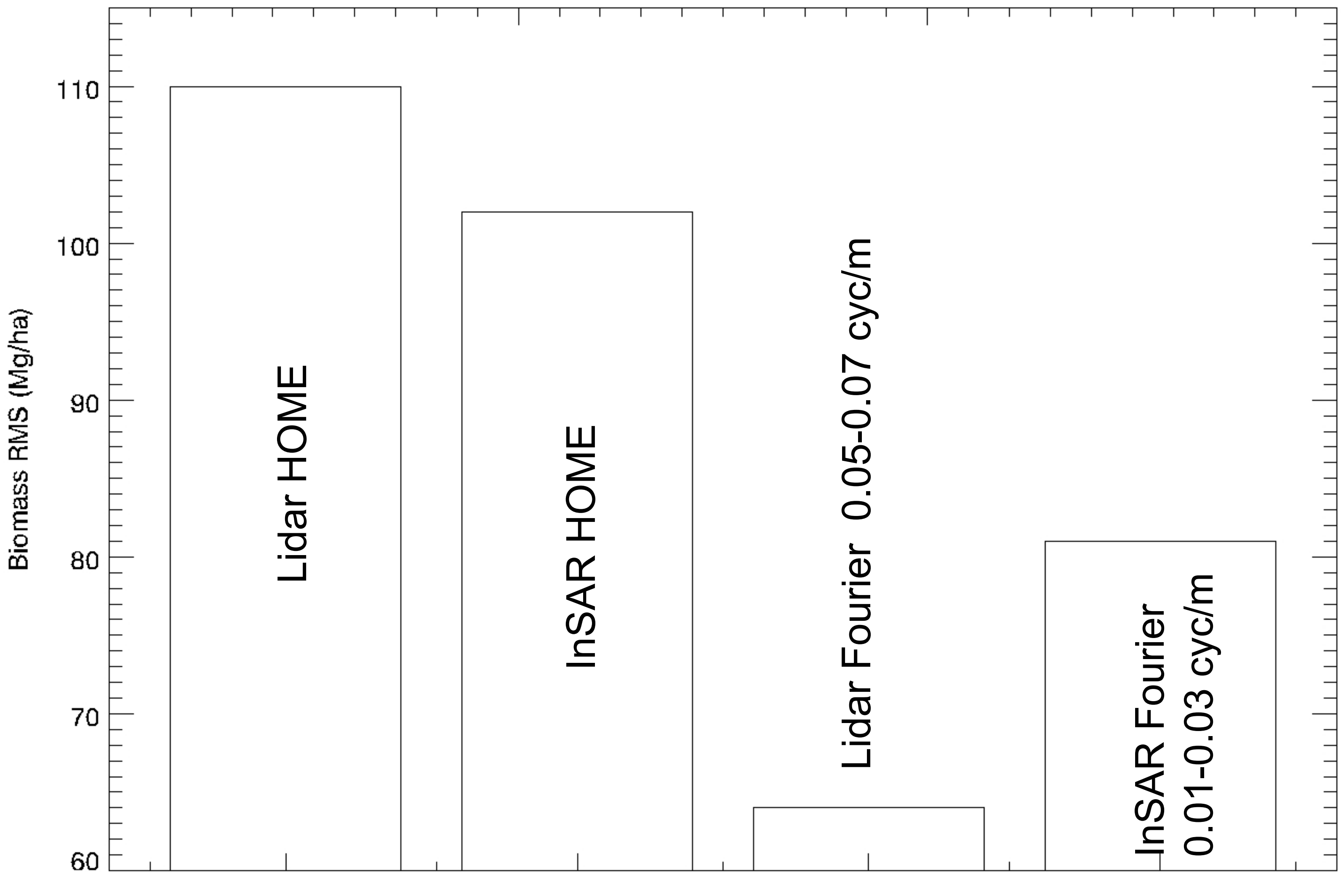

Biomass performance from lidar Fourier Frequencies 0.05-0.07 cyc/m :
All Biomasses<500 Mg/ha
RMS=64 Mg/ha
Average Percent=23
Biomass from Fourier Frequencies 0.05-0.07 cyc/m (Mg/ha)
Field Measured Biomass (Mg/ha)
0
100
200
300
400
500


Biomass performance as a Funciton of lidar Fourier Frequency
RMS Biomass Scatter (Mg/ha) Using 3 Lidar Fourier Frequencies
110
100
90
80
70
60
0.00
0.05
0.10
0.15
Lowest Frequency of 3, 0.01 cyc/m apart, Lidar (cyc/m)

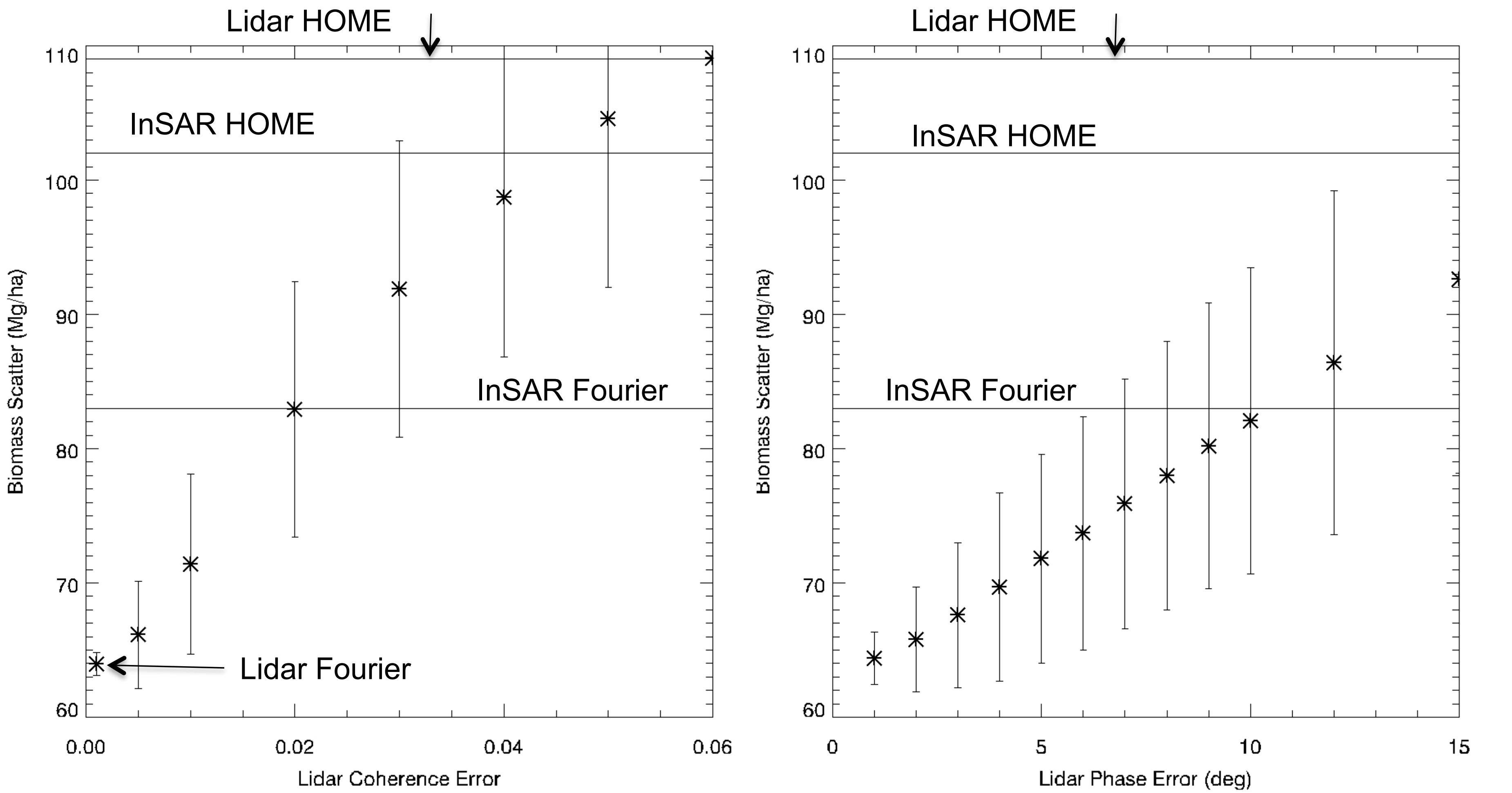
Biomass performance from InSAR Fourier Frequencies 0.01-0.03 cyc/m : All Biomasses<500 Mg/ha



Biomass performances from lidar and InSAR:
Can We Get InSAR-Fourier to the Lidar-Fourier Performance?



InSAR Coherence and Phase Requirements from Lidar+Simulated Noise: Making InSAR Biomass Estimates as Accurate as Lidar



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Results

- Lidar and InSAR (C-band) height produced >35% >100 Mg/ha biomass scatter
- Higher spatial frequencies from lidar (Fourier transformed) or InSAR (the data themselves) produce better results (<25%)
    - 64 Mg/ha lidar
    - 81 Mg/ha InSAR

- Three tightly clustered Fourier frequencies (3 baselines) with vertical wavelengths of 15-100 m produced the best results

- InSAR biomass estimate accuracy potentially equal to that of lidar:
    - InSAR coherence calibration better than 1%
    - InSAR phase calibration ~ 1 degree

To Do

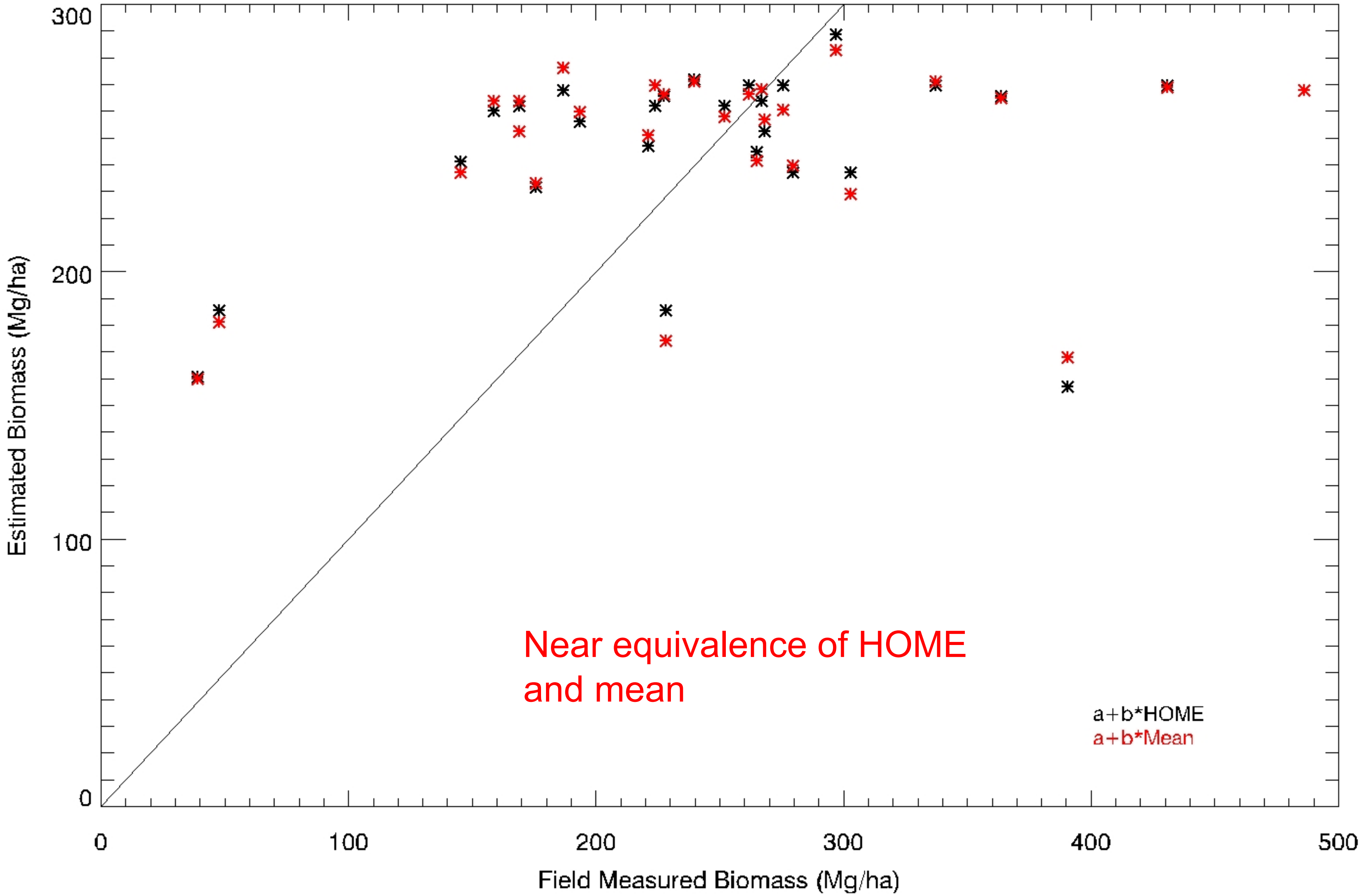
- L-band multibaseline polInSAR (for removing ground and isolating Fourier components)
- Repeat in other (tropical) forests

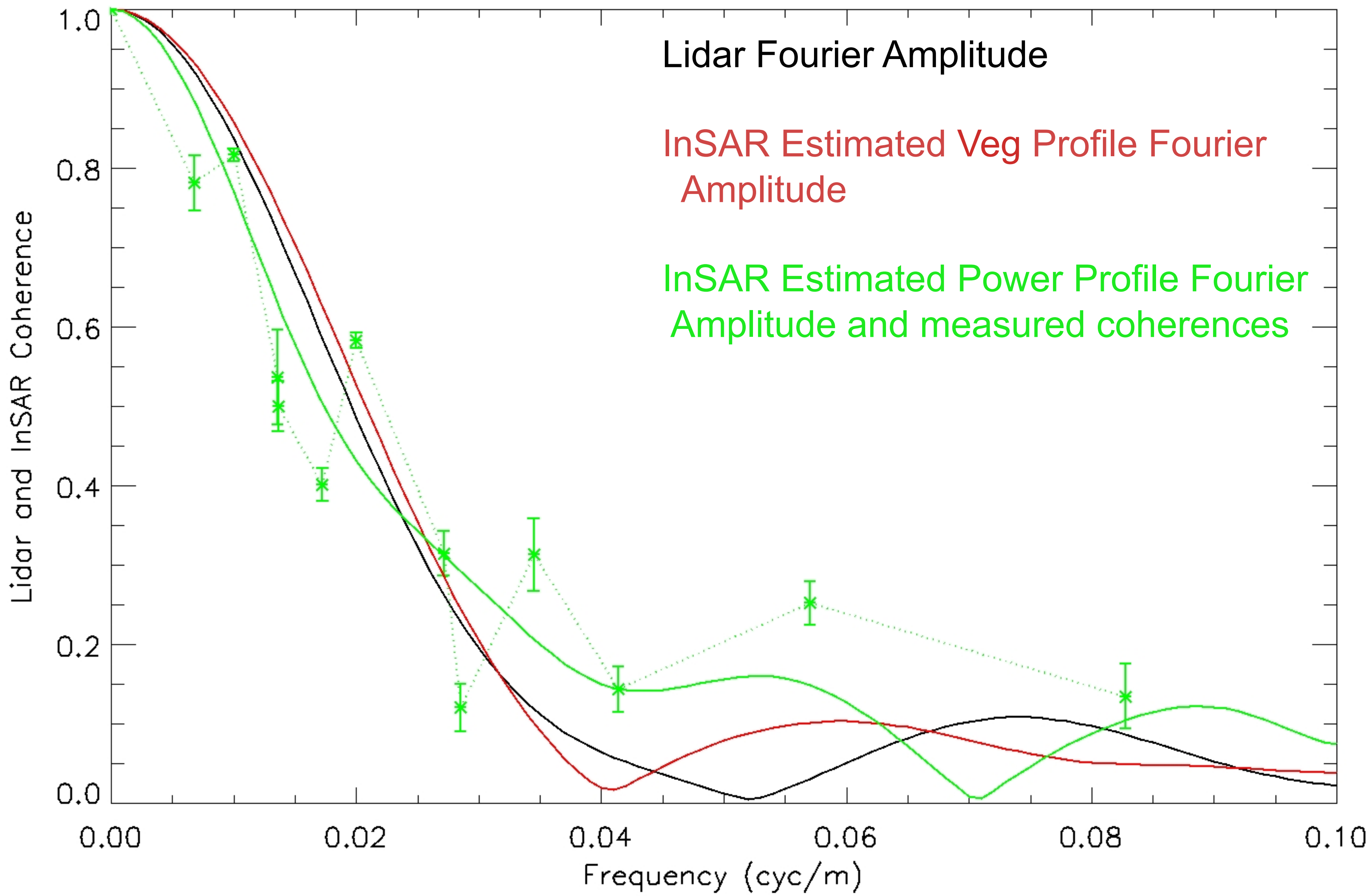
Tropical-Forest Calibration Requirements for Interferometric SAR by Comparison to Lidar in the Frequency Domain

To Do

- L-band multibaseline polInSAR (for removing ground and isolating Fourier components)
- Repeat in other (tropical) forests to explore robustness of parameter regression
  - La Selva is "wet" tropical, Amazon e.g. is "moist"
- Quantify differences between lidar and InSAR intrinsic performance
  - Given 1% and few degree calibration
- Derive dynamical model accounting for forest Fourier component "preference"

Biomass performance from lidar HOME and Mean




Lidar Fourier Amplitude
InSAR Estimated Veg Profile Fourier Amplitude
InSAR Estimated Power Profile Fourier Amplitude and measured coherences
Lidar and InSAR Coherence
Frequency (cyc/m)
0.00
0.02
0.04
0.06
0.08
0.10
0.0
0.2
0.4
0.6
0.8
1.0