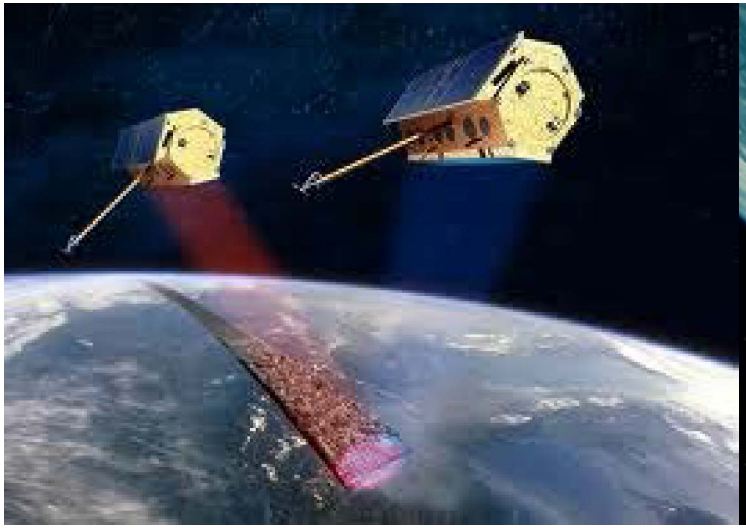
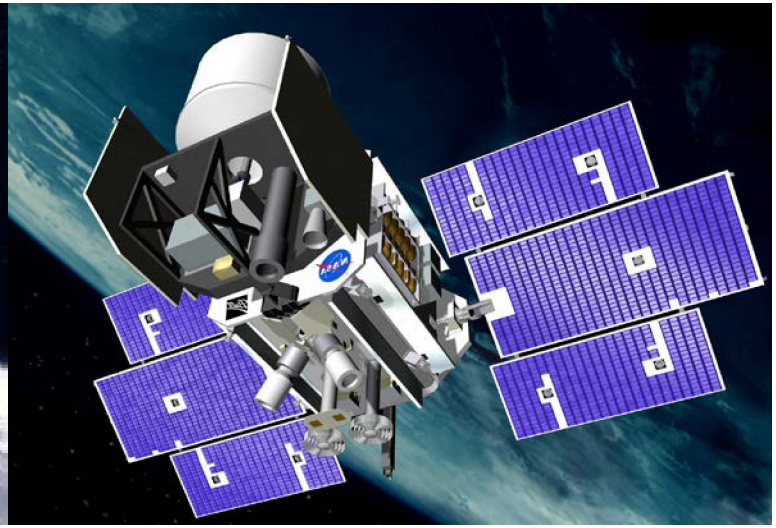
Satellite remote sensing of vegetation structure: Functional Synthesis of InSAR and Lidar





Robert Treuhaft[1], Maxim Neumann[1], Fabio Gonçalves[2], Michael Palace[3]

[1]Jet Propulsion Laboratory, California Institute of Technology

[2]Woods Hole Research Center

[3]University of New Hampshire

NASATerrestrial Ecology Science Team Meeting

05/01/2013– La Jolla, CA

Satellite remote sensing of vegetation structure: Functional Synthesis of InSAR and Lidar

The electromagnetic wave and the cosine

Interferometric phase and coherence: one,two, many scatterers

InSAR as Fourier transform per baseline, and lidar Fourier transformed

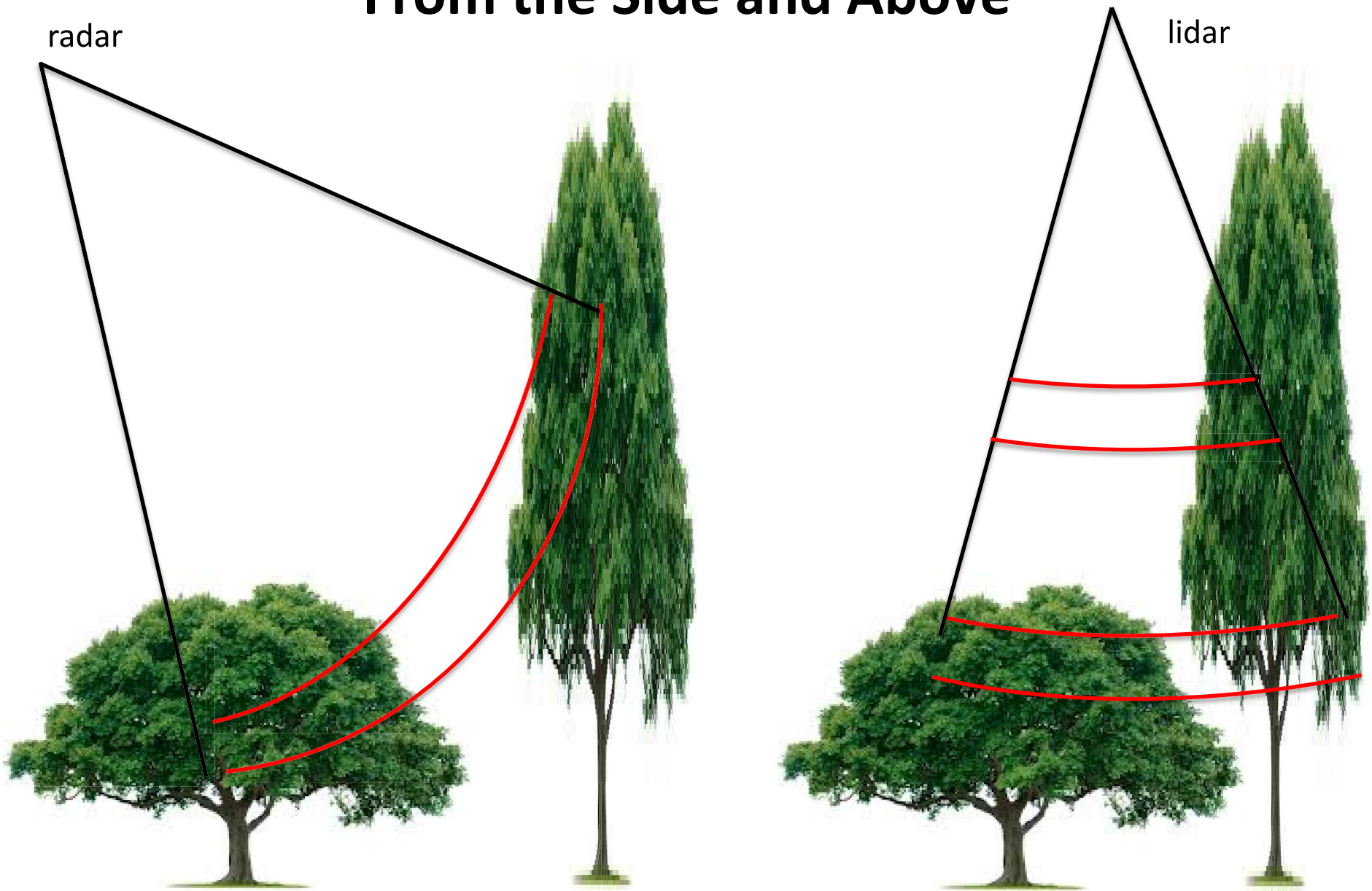
InSAR: Coverage rich, Fourier poor Lidar: Fourier rich, coverage poor

Can lidar Fourier transforms (baselines) inform InSAR for global monitoring?

Contributors: Greg Asner, Bryan Blair, Bruce Chapman, Yuri Knyazikhin, Michael Keller, Paul Moorcroft, Doug Morton, Jacqueline Rossette, Marc Simard, Paul Siqueira, Lee Vierling

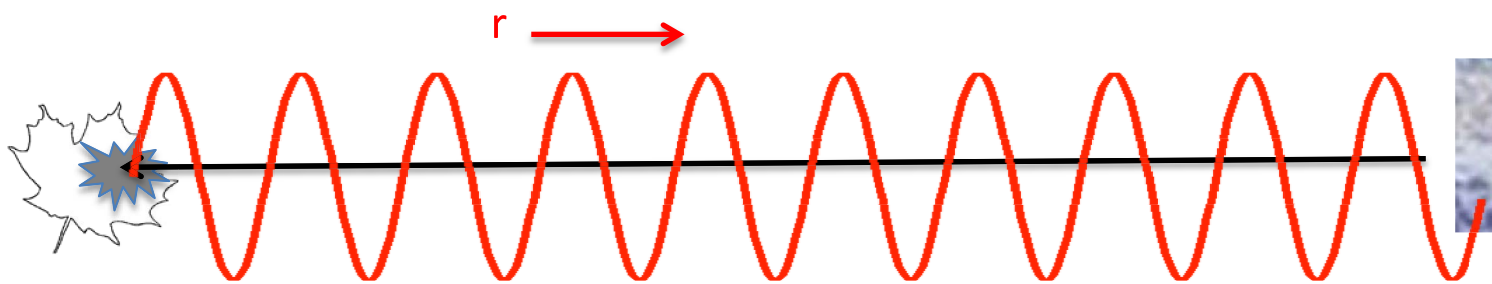
The Range Bite and Veg Height

From the Side and Above



InSAR: The Electromagnetic Field, Phasors,

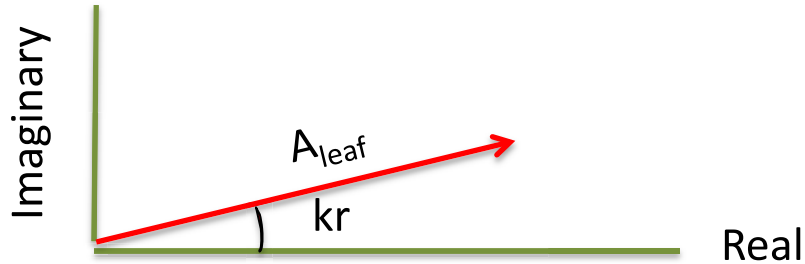
The Interferometer and Height



Received field= $A_{leaf}\cos(\frac{360}{\lambda}r-\omega t)=A_{leaf}\cos(kr-\omega t)$ REAL!

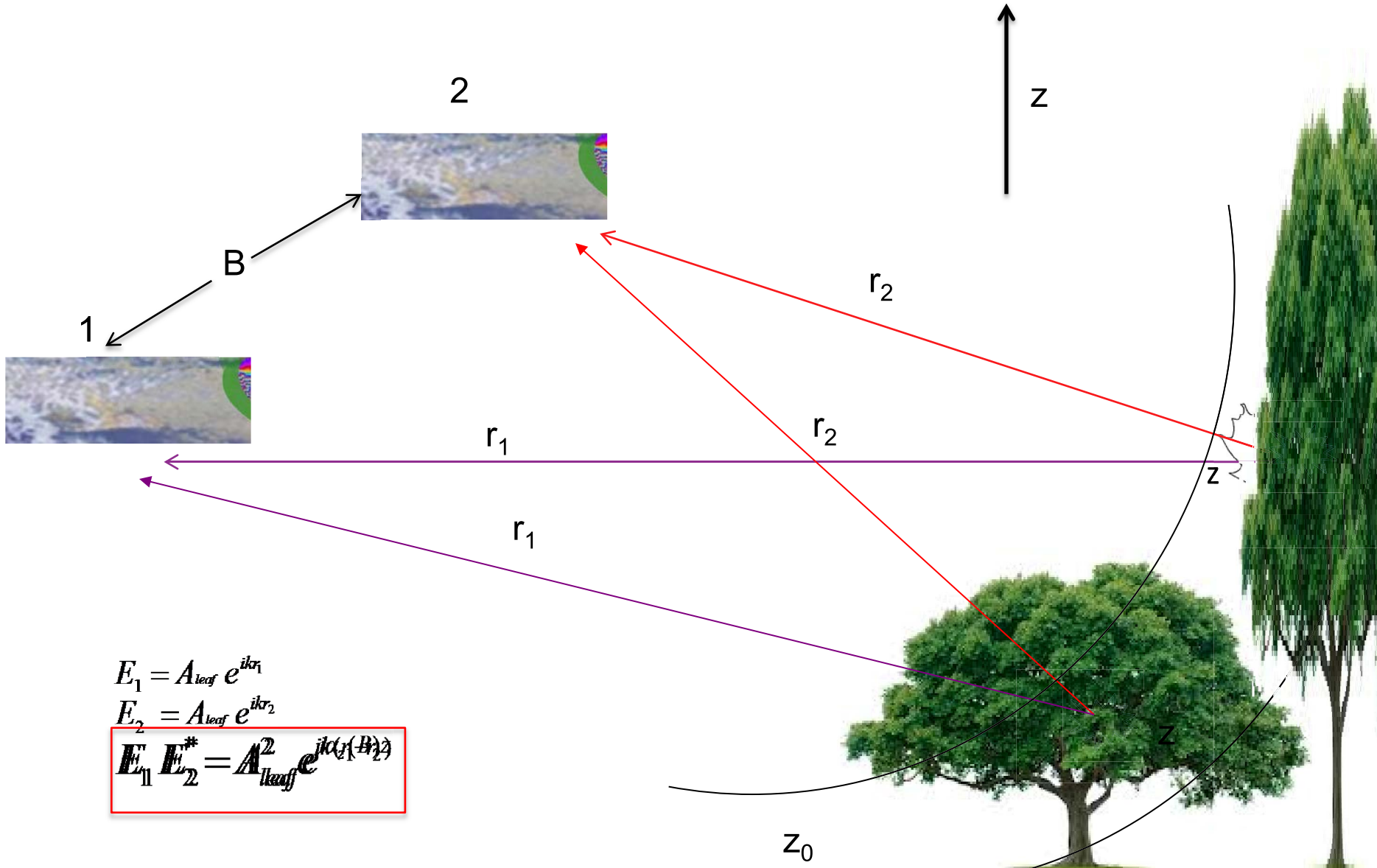
Signal processing

$$E=A_{leaf}[\cos kr+i\sin kr]=A_{leaf}e^{ikr}$$ The phasor COMPLEX!



InSAR: Single Scatterer

Interferometeric Phase and Height: SRTM/Topo



$$E_1 = A_{leaf}\, e^{ikr_1}$$

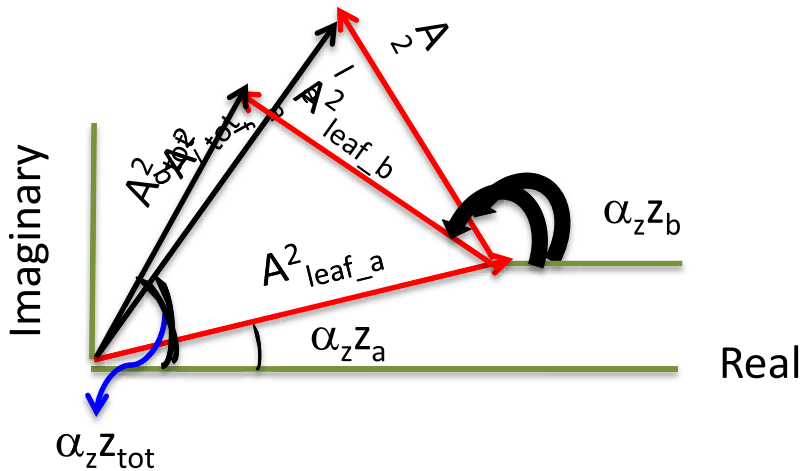
$$E_2 = A_{leaf}\, e^{ikr_2}$$

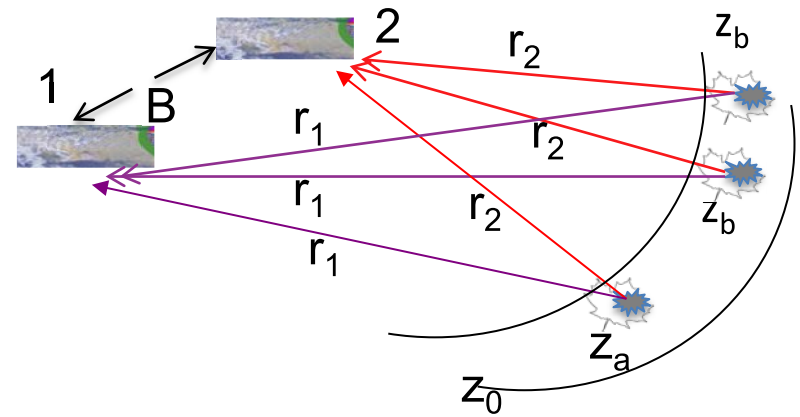
$$\boxed{E_1 E_2^* = A_{leaf}^2\, e^{ik(r_1 - r_2)}}$$

InSAR: Two Vegetation Scatterers

InSAR Phase and Coherence: Terrestrial Ecology

$$E_1 E_2^* = \left[A^2_{leaf_a} e^{i\alpha_z(B) z_a} + A^2_{leaf_b} e^{i\alpha_z(B) z_b} \right]$$





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**

InSAR: Many Vegetation Scatterers

The Fourier Transform and Big Time TE

$$E_1 E_2^* = \left[A^2_{leaf_a} e^{i\alpha_z(B) z_a} + A^2_{leaf_b} e^{i\alpha_z(B) z_b} + \ldots \right] \longrightarrow \int_0^\infty A^2(z)\ e^{i\alpha_z z}\ dz \equiv FT(\alpha_z(B))$$

InSAR is the **Fourier transform** of the vertical radar power profile, with **spatial frequency α_z** for baseline B

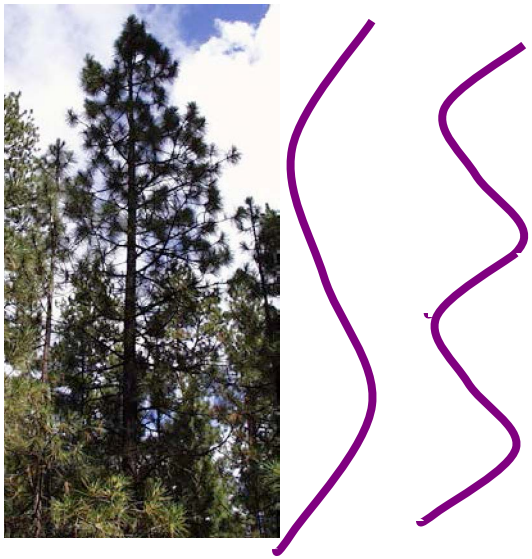
It is frequently normalized to produce the fundamental InSAR obs, the complex coherence

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

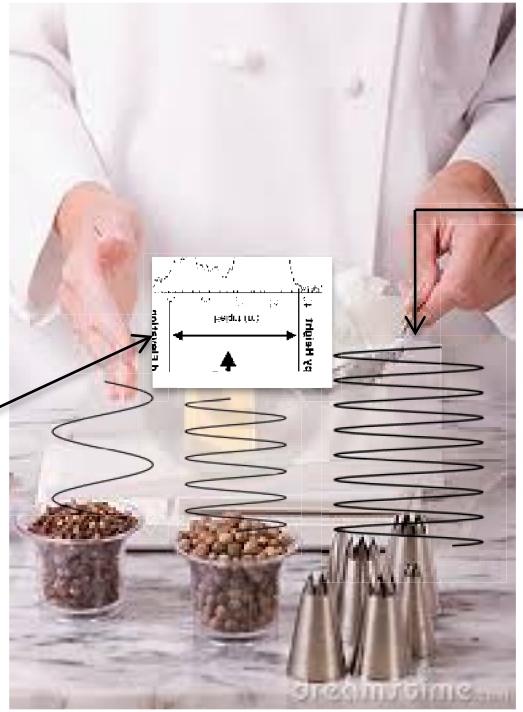
The Fourier Transform

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

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



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



Lidar
Drake et al. 2002
Fourier rich

InSAR
Fourier poor

The Fourier Transform:

Two Things

1) With an infinite number of Fourier frequencies (Baselines), any profile can be determined:

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

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

2) Derivatives of the FT with respect to frequency, near zero frequency, give profile weighted averages, standard devs, profile moments…:

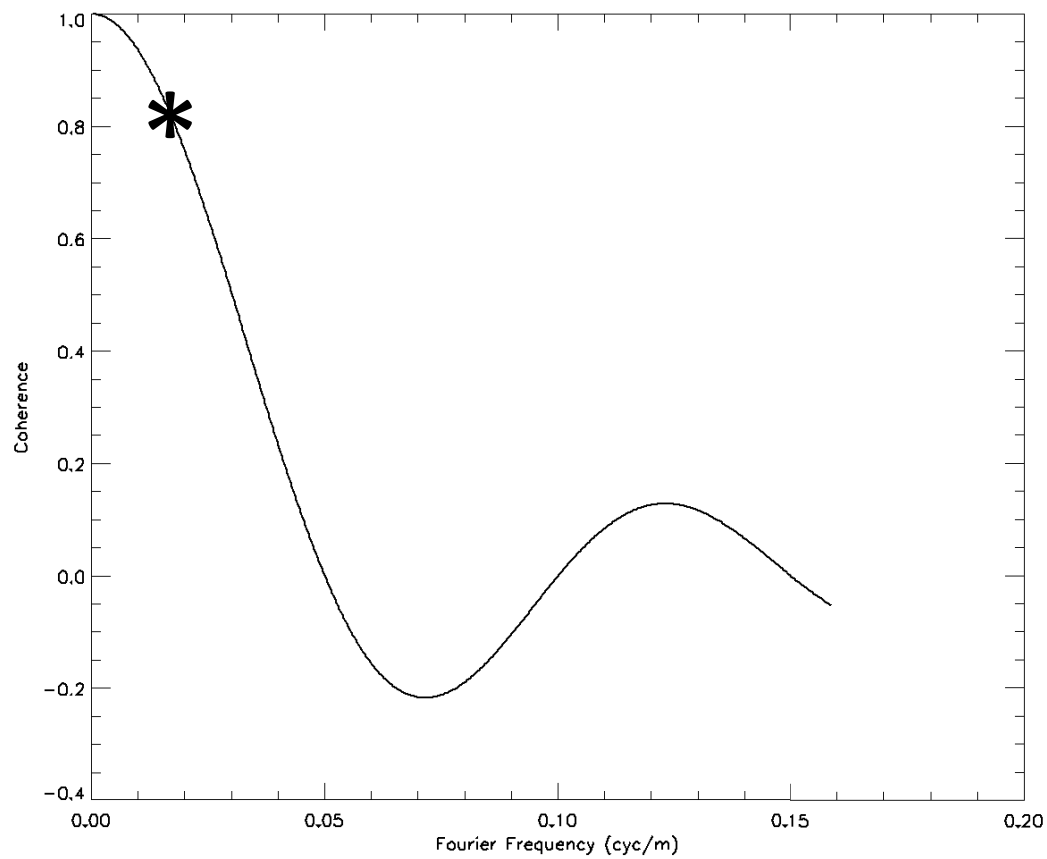
$$\lim_{\alpha_z \to 0} \frac{d\gamma(\alpha_z(B))}{d\alpha_z} = \frac{\int_0^\infty iz\ A^2(z)\ e^{i\alpha_z z}\ dz}{\int_0^\infty A^2(z)\ dz} = i\ \bar{z}$$

The Fourier Transform: Profile Models And a Small # of Baselines

InSAR frequently relies on a model to stitch together the Fourier frequencies it did not measure:

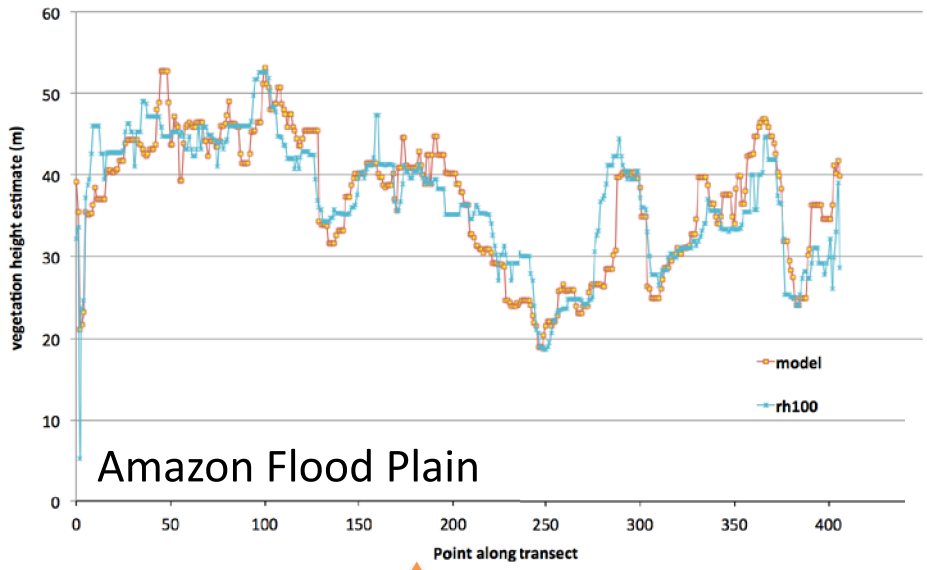
1) Uniform density up to top height (Chapman, 2013)
2) Exponential w/attenuation (Treuhaft et al. 1996)
3) Exponential with ground (Papathanassiou, Cloude, 2001)
4) Gaussian density (Treuhaft et al. 2002)
5) Legendre polynomials (Cloude 2006)

Coherence w/Uniform Density



Profile Models Used with Small #s of Baselines

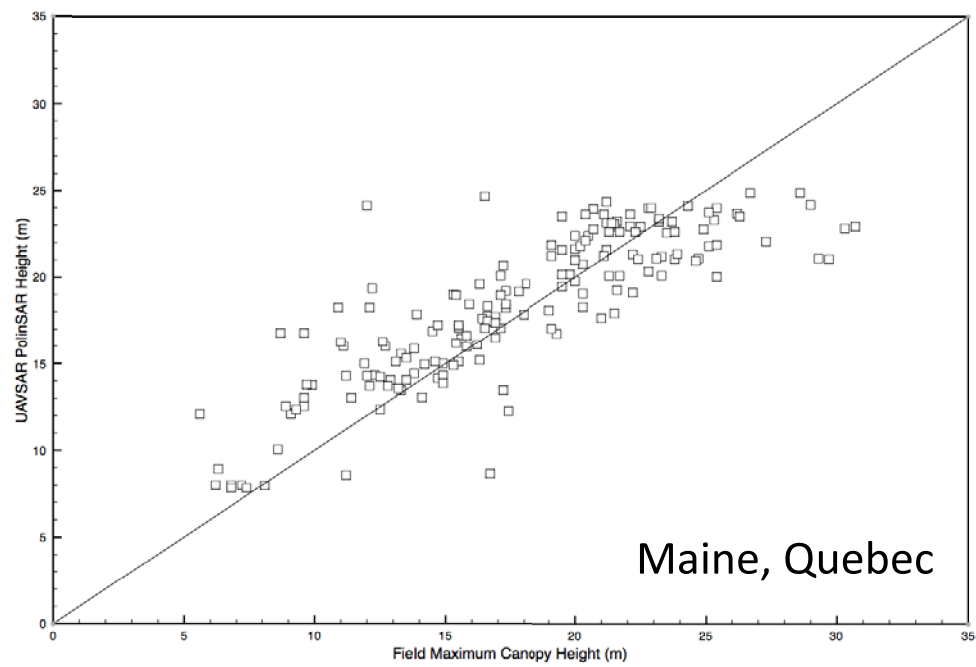
Veg Height from C-band SRTM Coherence



Fourier constrained so 1 baseline determines all others (courtesy B. Chapman et al.)

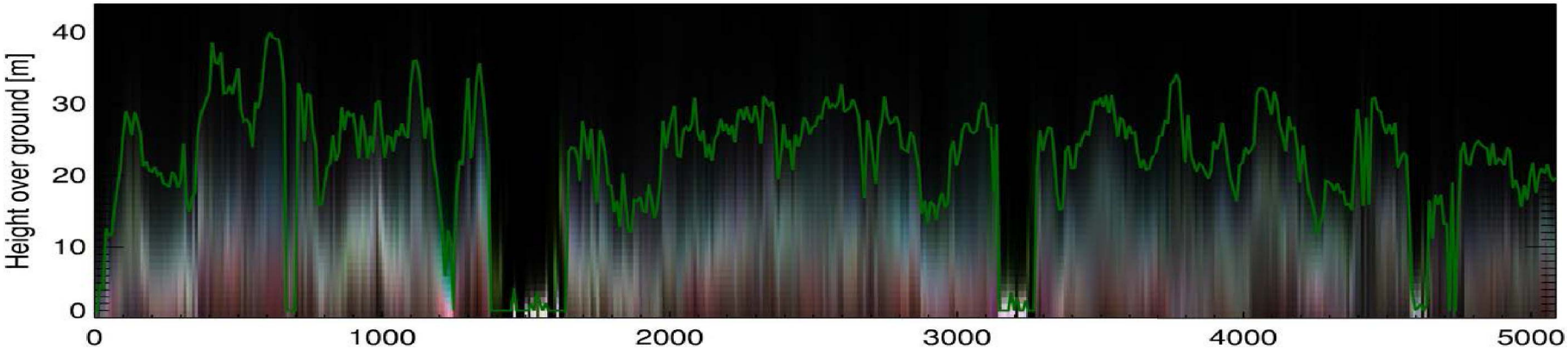
Fourier constrained so 1 (polarimetric) baseline determines all others (courtesy M. Simard et al).

Veg Height from L-band UAVSAR



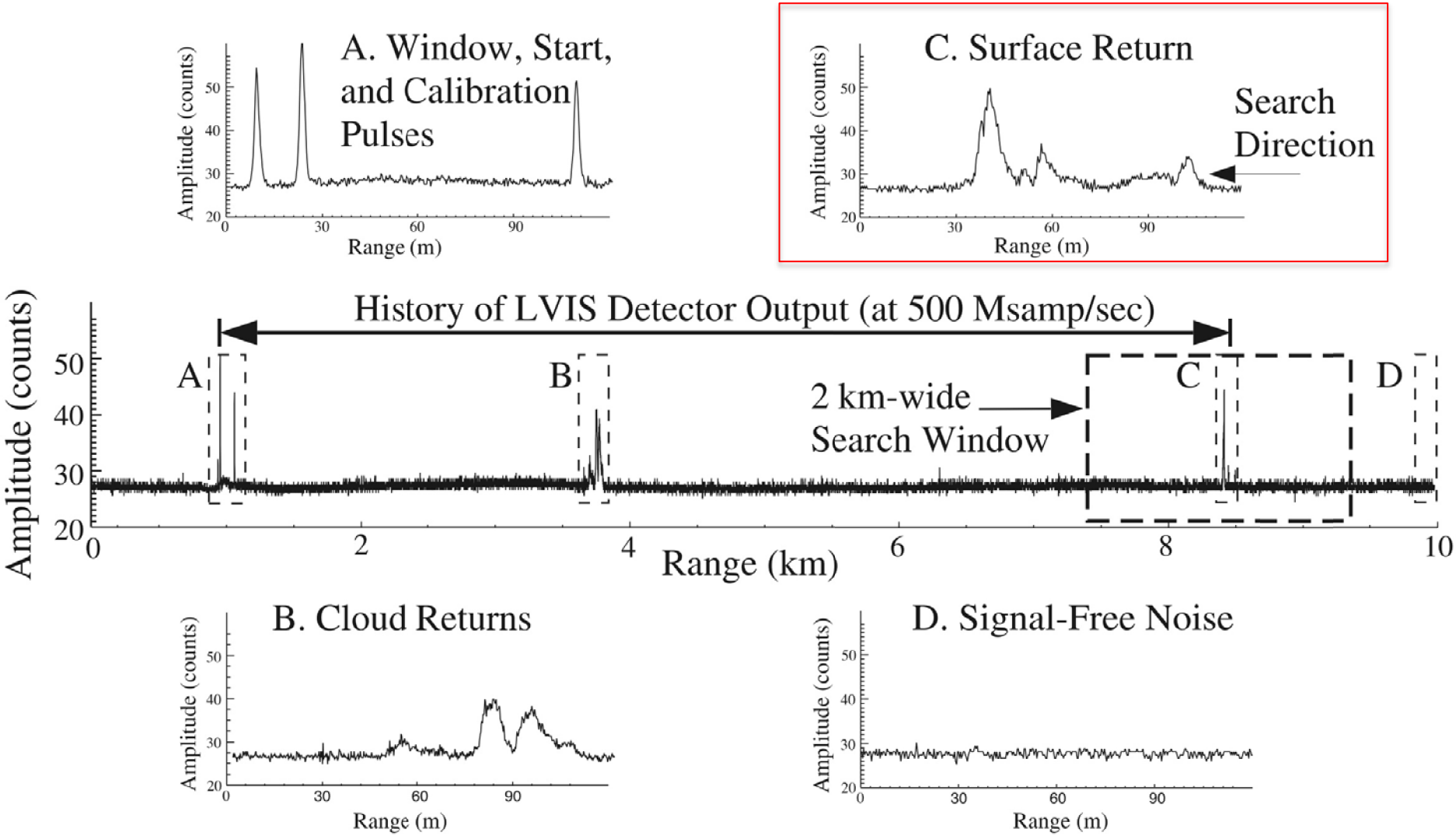
Less Constrained with Larger # of Baselines

JPL's UAVSAR sensor – Harvard Forest dataset–L-band



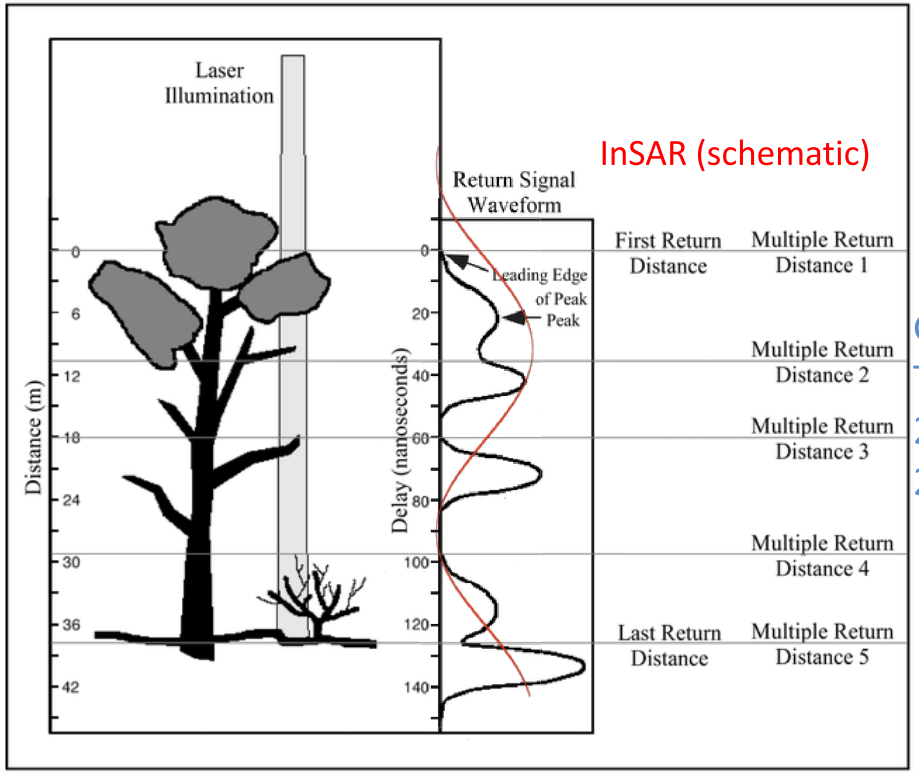
Tomography: ~Inverse Fourier transform, relatively unconstrained with 4 (polarimetric) baselines (courtesy M. Neumann, S. Hensley et al.)

Lidar Vegetation Returns



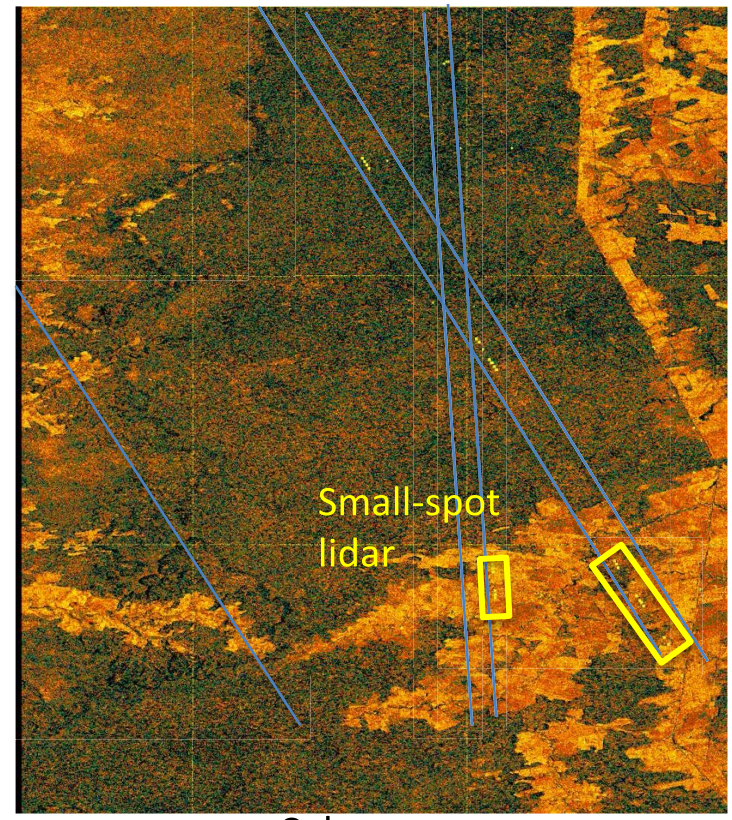
Blair et al. 1999

Lidar, Fourier, and Coverage

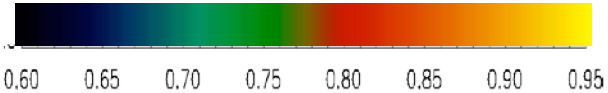


Lefsky et al. 2002

TanDEM-X InSAR Coherence (2011)
Tapajos, Brazil



Coherence



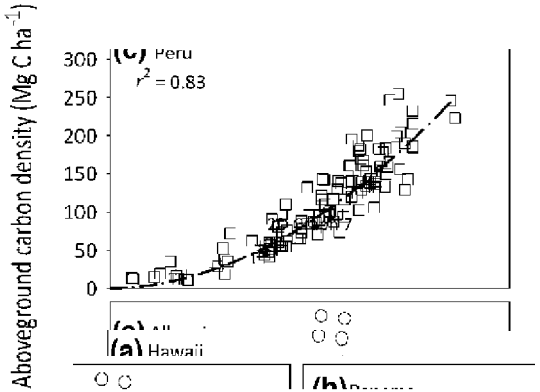
20 x 36 km

- Lidar is Fourier rich, coverage poor
- InSAR is coverage rich, Fourier poor

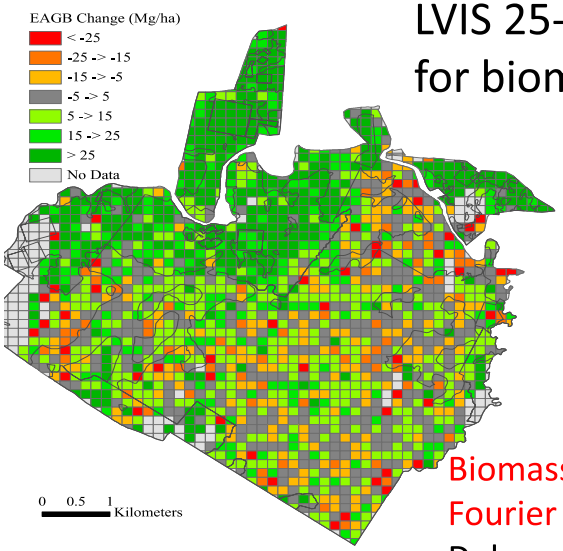
Lidar Ecosystem Descriptors:

What Fourier Frequencies are Used?

CAO 1.12-m lidar for biomass

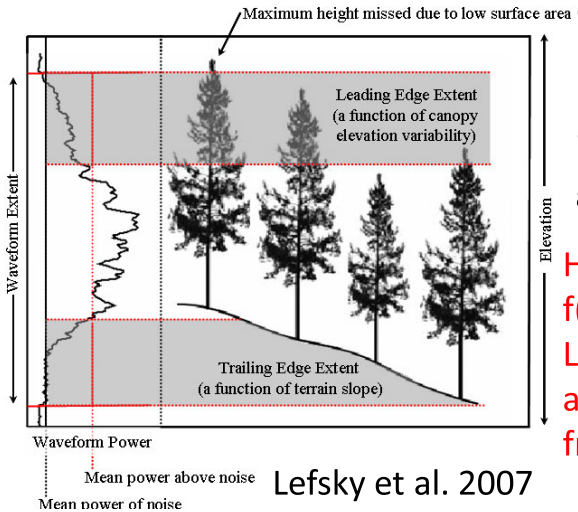


Biomass=f(Mean canopy height),
Fourier freq near 0, Asner et al. 2011



LVIS 25-m Lidar
for biomass, La Selva

Biomass=f(ΔRH_E50,ΔRH_E100),
Fourier freq~zero?
Dubayah et al. 2010

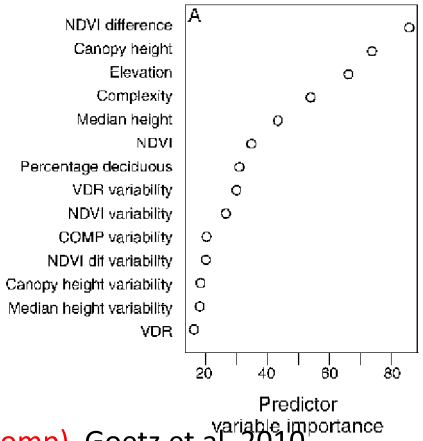


GLAS 70-m
For Height
and biomass,
global

Height(biomass)=
f(wf extent (fr~0),
Leading edge,
and trailing edge
fr=?)

Lefsky et al. 2007

LVIS for habitat quality,
Hubbard Brook, NH

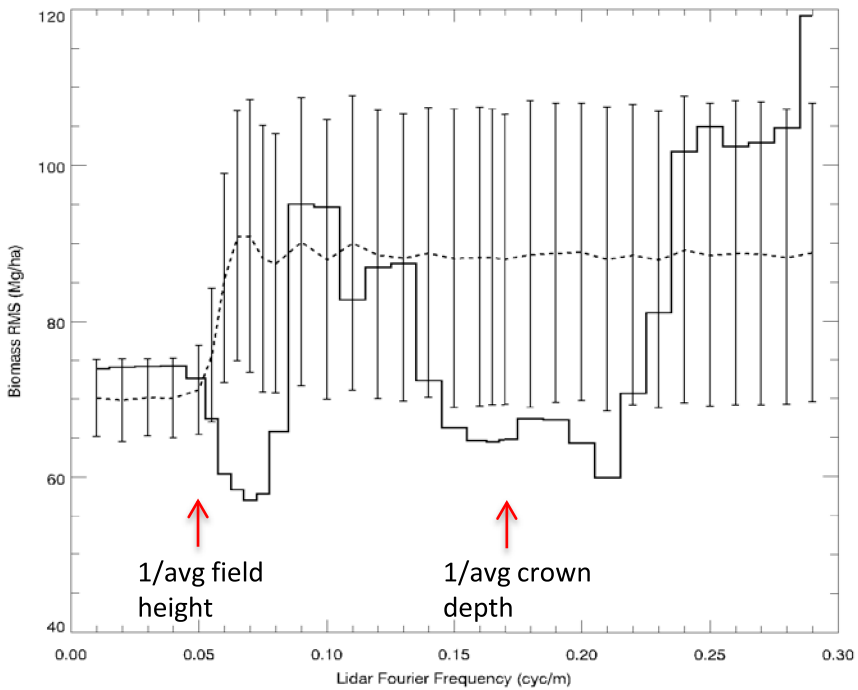


Abundance=f(height, med height, comp), Goetz et al. 2010
fr~0, fr~0, fr~?

Lidar Ecosystem Descriptors:

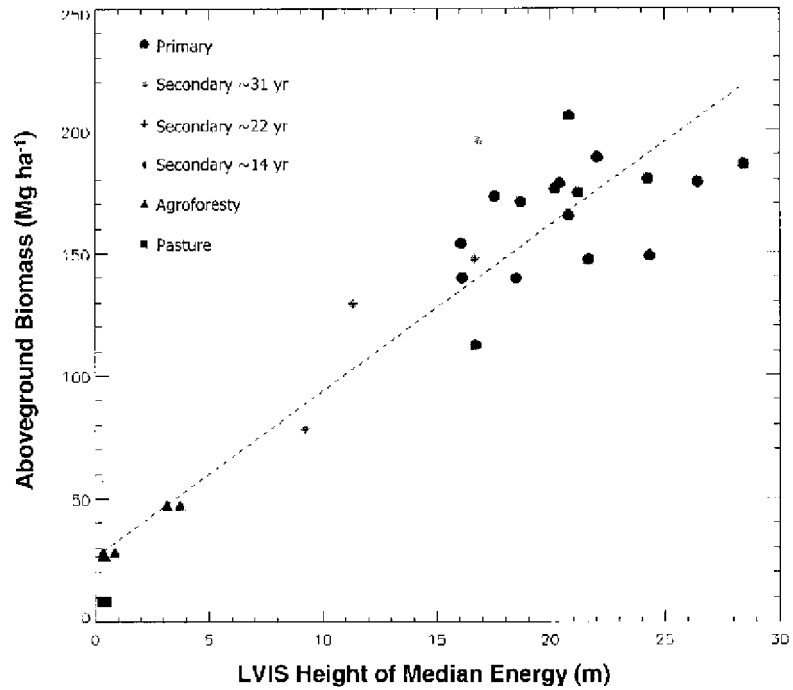
What Fourier Frequencies are Used?

LVIS 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)

LVIS Biomass La Selva



Biomass=a+b*height of median energy
Fourier freq~0, Drake et al. 2002

Can Lidar Be Used to Inform InSAR Frequencies?

Lidar Waveform

↓

Fourier transform
at many frequencies

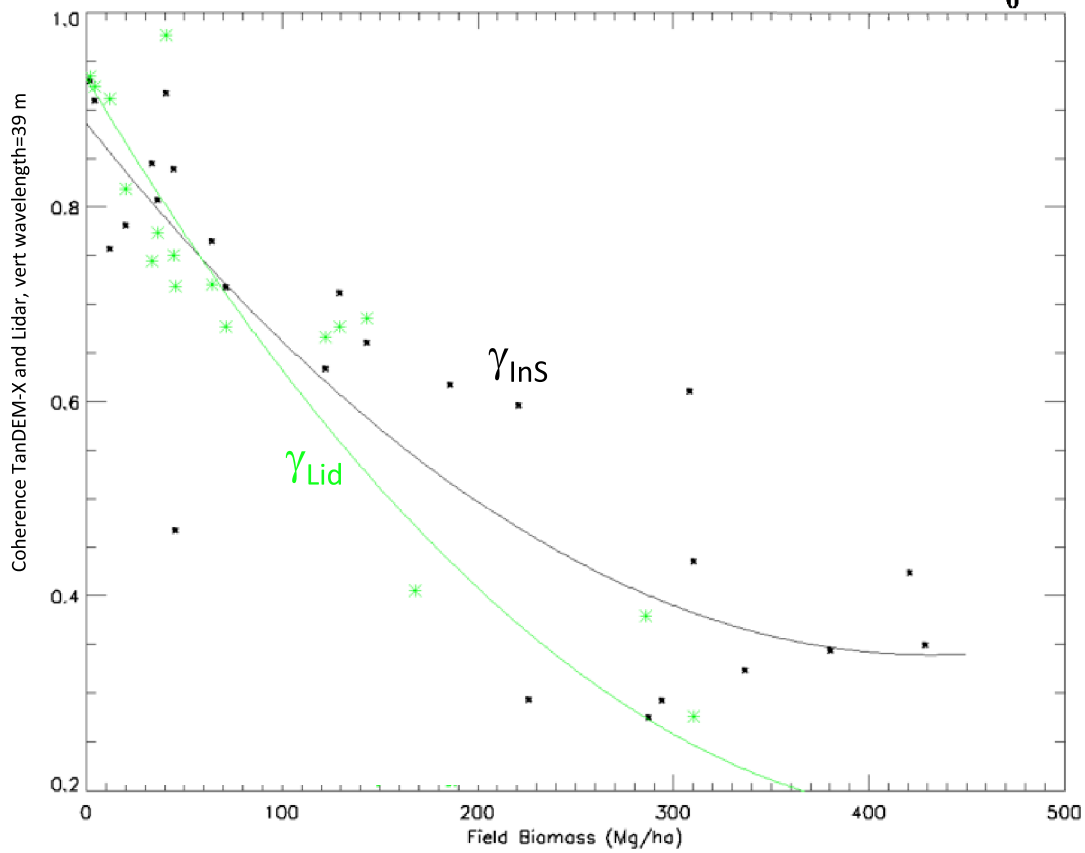
↓

Optimal lidar Fourier frequencies
→Optimal InSAR baselines

Can Lidar Be Used to Inform InSAR Frequencies?

$$\gamma_{InS}(\alpha_z(B)) = \frac{\int_0^\infty A^2(z)\ e^{i\alpha_z z}\ dz}{\int_0^\infty A^2(z)\ dz}$$ InSAR

$$\gamma_{Lid}(\alpha_z) = \frac{\int_0^\infty w(z)\ e^{i\alpha_z z}\ dz}{\int_0^\infty w(z)\ dz}$$ Lidar



TanDEM-X X-band InSAR and Small-Footprint (30 cm) Lidar in Brazil

Fourier and Biomass Dynamics

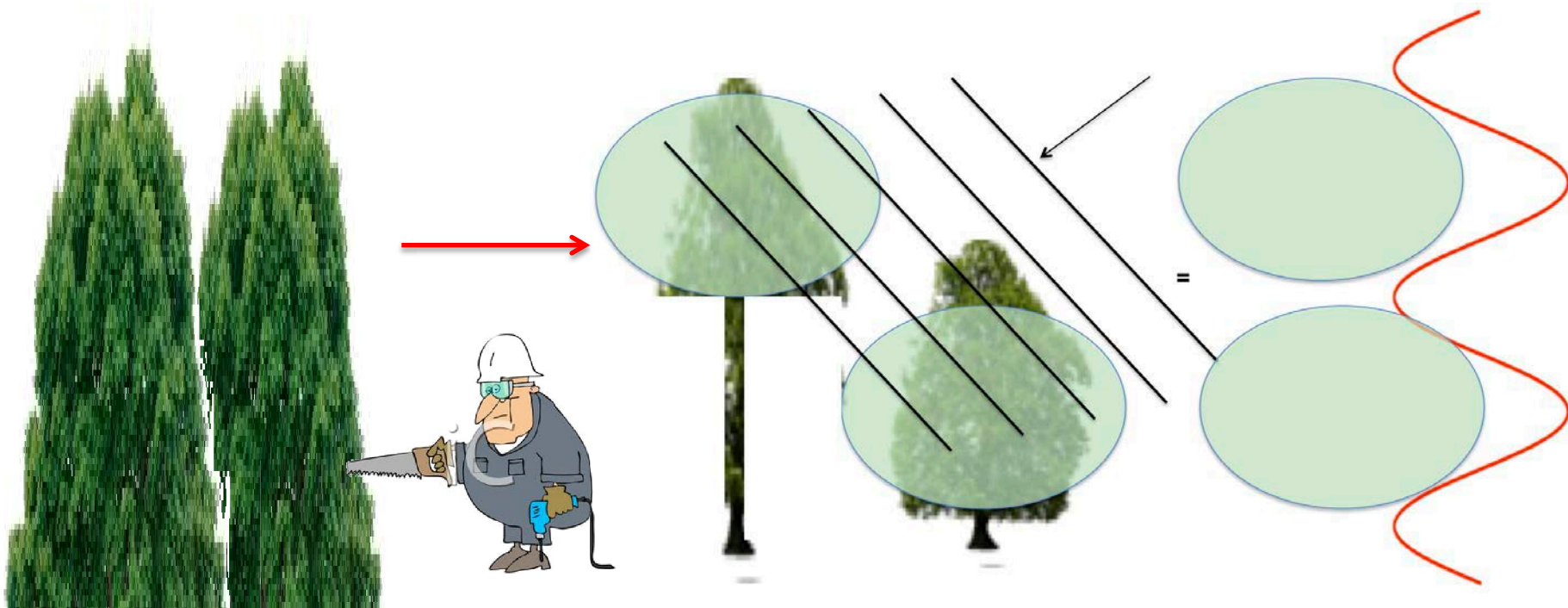
InSAR is a Fourier transform

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

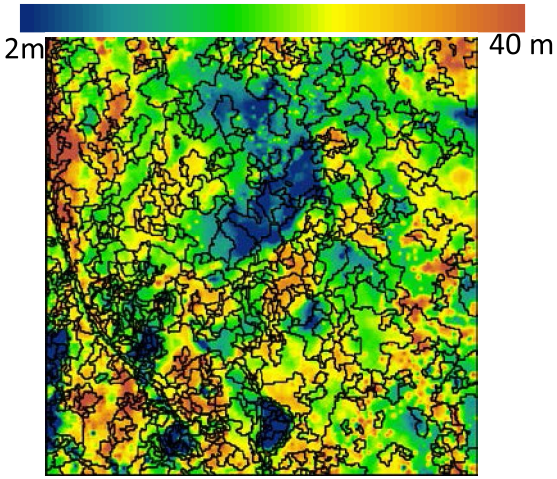
Modeling Opportunity: The “small push” response of a system in equilibrium is sinusoidal

The frequency of oscillation depends on the forces that maintain equilib

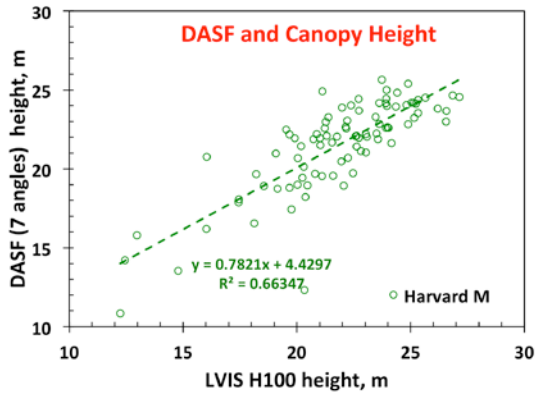
The size of the oscillation sheds light on the force (disturbance)



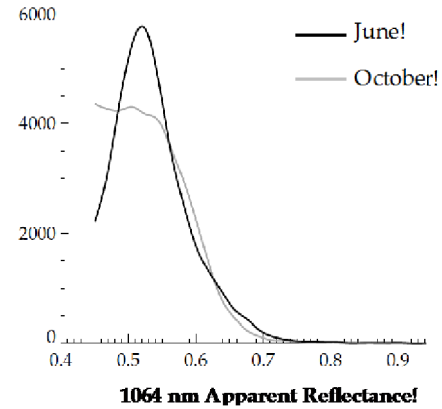
Fusion and New Technologies



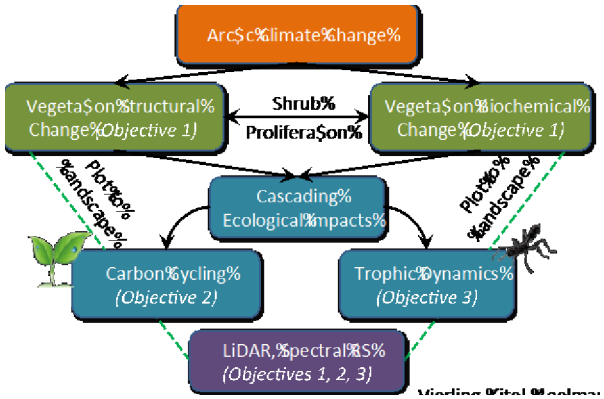
Polarimetric SAR to segment lidar heights, northeast US, Siqueira, Umass



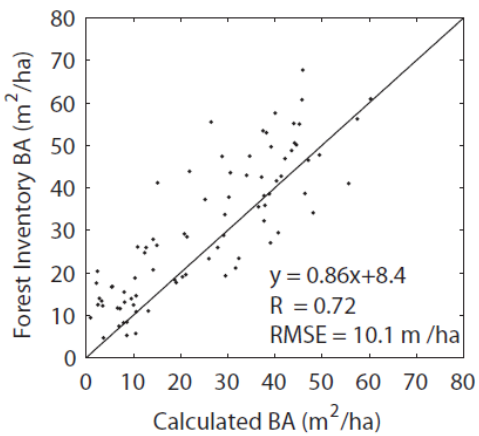
Directional area scattering factor from MISR and hyperspectral, Knyazikhin, Boston U



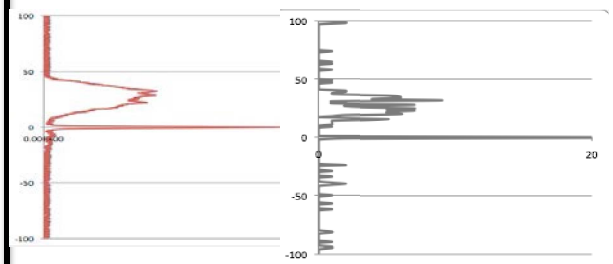
Lidar (GLAS) reflectance to supplement structure for phenology and disturbance, Morton, Goddard



Monitoring plant and insect species shifts with lidar and multispectral data, Vierling, U. Idaho



Combining hyperspectral and lidar for composition and structure for use in ED2, Harvard Forest, Moorcroft, Harvard U

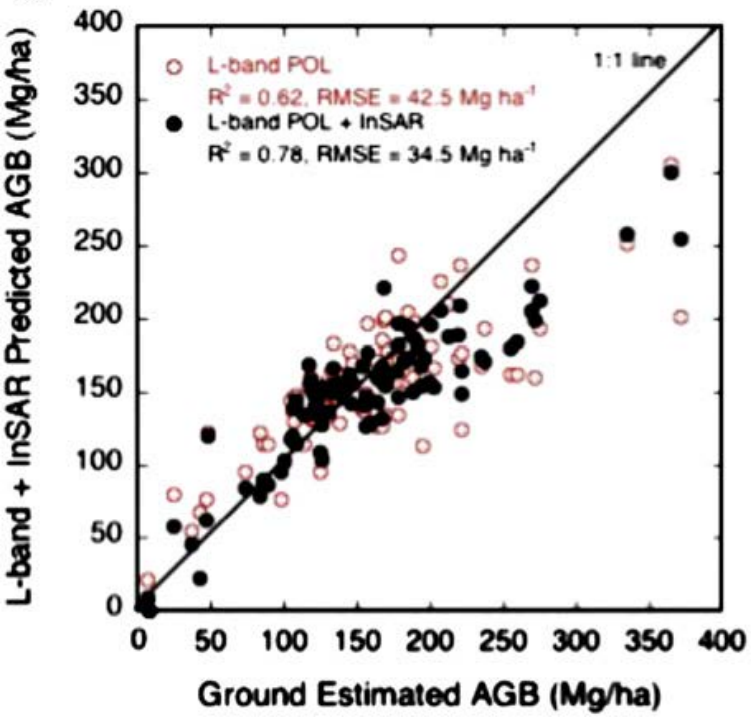


GLAS (ICESat-1) (1064nm)

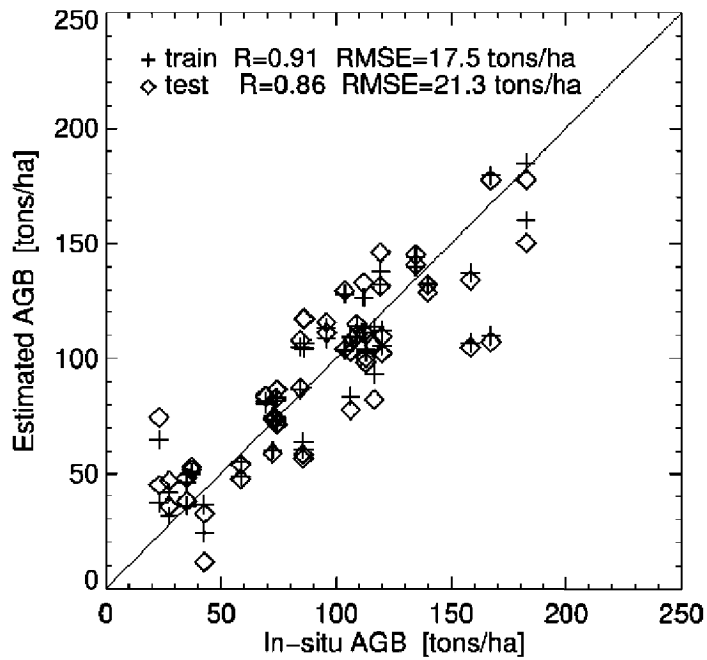
ATLAS (ICESat-2) (532nm)

FLIGHT simulations (P. North, Swansea U) to understand photon counting ICESat-2 profiles, Rosette, Goddard

Fusion and New Technologies



Combining L-band radar polarimetry and C-band InSAR phase height, Saatchi 2011



Combining L-band polarimetry and PolInSAR height, Neumann 2012

Summary

- The electromagnetic wave and the cosine
- InSAR: One scatterer (SRTM-topo) Two scatterers (Terrestrial Ecology)
- Many scatterers→InSAR is the Fourier transform of the vertical radar power, one Fourier frequency per baseline
- Lidar is Fourier rich, coverage poor
- InSAR is coverage rich, Fourier poor
- The Fourier frequencies used by InSAR (stitching baselines) and lidar (~0?)
- Can lidar be used to inform InSAR frequencies/baselines for global monitoring?
- Fourier and biomass dynamics
- Fusion techniques and new technologies

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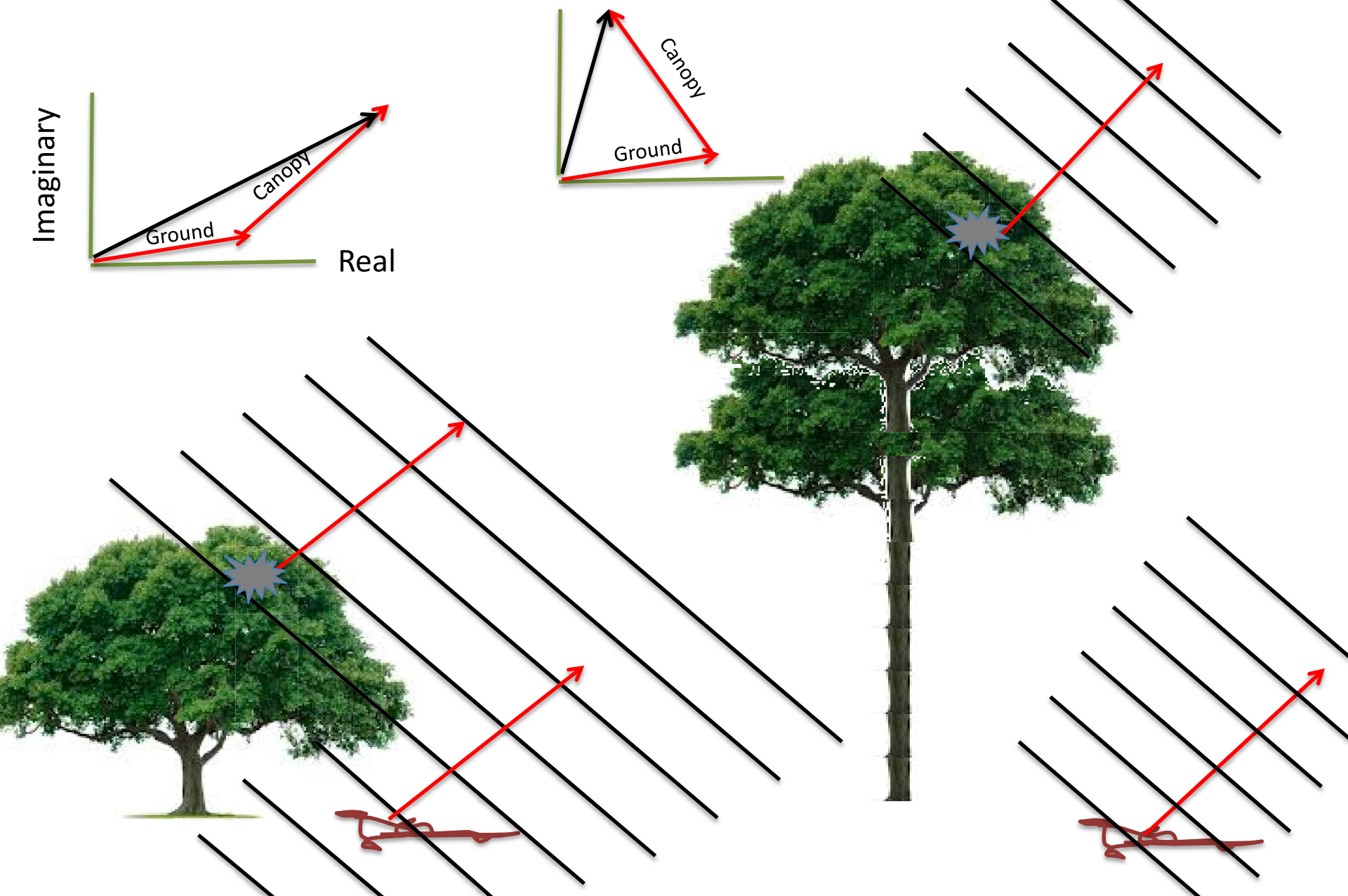
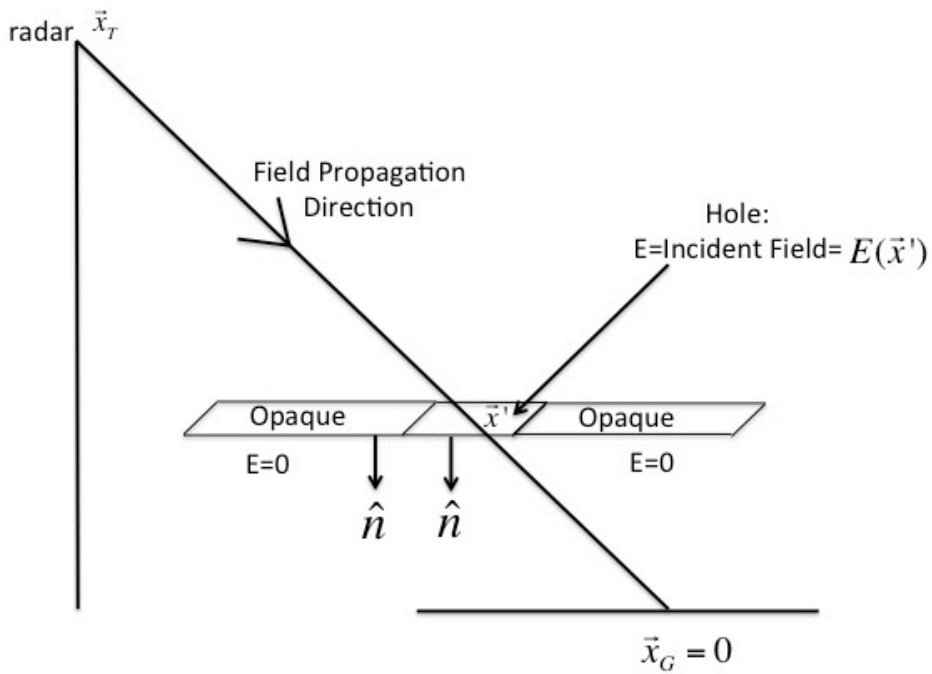
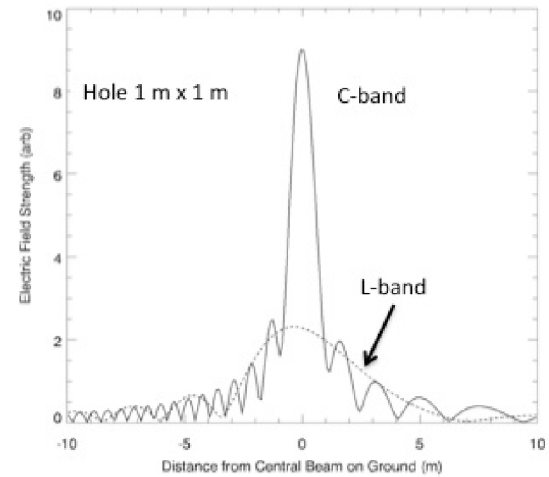
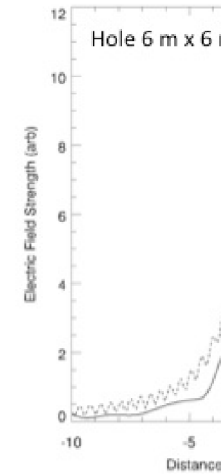
InSAR and Saturation

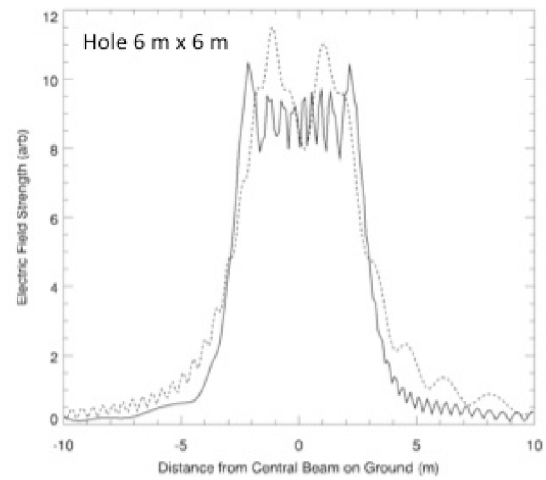


Can InSAR and Lidar Penetrate Similarly: Holes

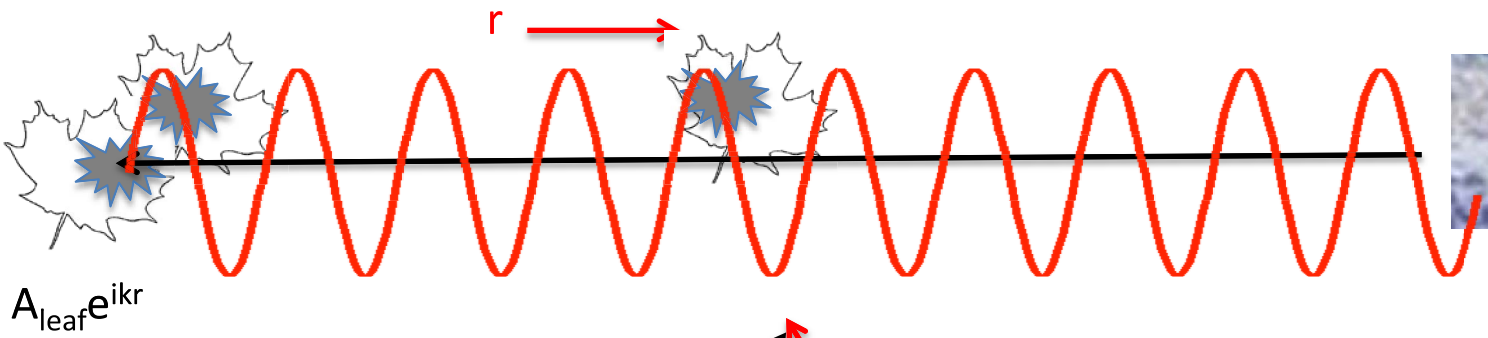


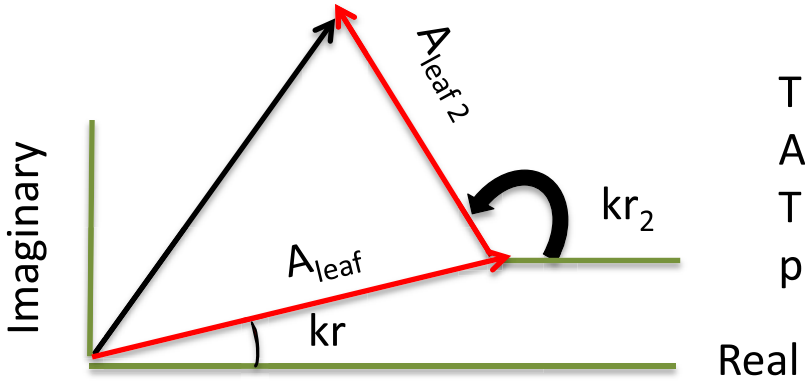






Adding Fields (Phasors) from Veg





The fields (phasors)
Add vectorially on
The complex (x,y)
plane

Satellite remote sensing of vegetation structure: Functional Synthesis of InSAR and Lidar

InSAR and lidar, from the side and from above

The electromagnetic wave and the cosine

Interferometric phase of a single scatterer→SRTM and topography

Interferometric phase and coherence of two or more scatterers→Terrestrial Ecology

InSAR as Fourier transform, limited baselines, and lidar Fourier transformed

InSAR: Coverage rich, Fourier poor Lidar: Fourier rich, coverage poor

Can lidar Fourier transforms (baselines) inform InSAR for global monitoring?

Contributors: Greg Asner, Bryan Blair, Bruce Chapman, Scott Hensley, Yuri Knyazikhin, Michael Keller, Paul Moorcroft, Doug Morton, Jacqueline Rossette, Marc Simard, Lee Vierling