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EcoSAR: a P-band Interferometric Synthetic Aperture Radar for Forest structure and biomass measurements

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Introduction

Climate change constitutes the greatest environmental problem of this century and is destined to significantly impact all societies. Quantifying the carbon cycle is the most important element in understanding climate change and its consequences, yet is poorly understood. Forests store 85% of terrestrial carbon, yet the amount of carbon contained in the earth's forests is not known to even one significant figure, ranging from 385 to 650 10^{15}g carbon (Saugier et al. 2001, Goodale et al. 2002, Houghton et al. 2009). The National Research Council's Decadal survey prioritizes the need to accurately close the carbon budget. Terrestrial biomass (woody mass per unit area), ecosystem structure (height and density) and extent need to be quantified on a global scale and with meaningful frequency to account for changes from both natural and human-induced disturbances. This can only be done efficiently and uniformily through remote sensing.

In this presentation, we will introduce the EcoSAR concept, an airborne Polarimetric and Interferometric P-band Synthetic Aperture Radar (SAR) instrument, and it's scientific objectives. EcoSAR will provide two- and three-dimensional fine scale measurements of terrestrial ecosystem structure and biomass. Synthetic Aperture Radar (SAR) illuminates the vegetation with microwave energy at an angle that interacts with vegetation structure and ground and senses the entire vegetation volume and density (i.e. biomass). P-Band SAR (0.3 - 1 GHz or 30 - 100 cm wavelength) measures forest biomass directly up to 200 Mg/ha (Megagrams per hectare) with $\pm$10% accuracy because of the longer wavelengths and deeper penetration into the canopy, whereas L-band biomass measurements saturate at a maximum of 140 Mg/ha (Mougin, 1999). Many tropical and temperate forests' biomasses can reach up to 600 Mg/ha, which cannot be measured with current SAR capabilities. Interferometric SAR (InSAR) and Polarimetric InSAR (PolInSAR) are able to measure vegetation structure and biomass, without any saturation at longer wavelengths.

Our EcoSAR instrument concept will provide P-band Polarimetric InSAR data, which will quantify ecosystem structure and biomass at high resolution and low error. The following figure shows NASA's P3 aircraft with the EcoSAR instrument and an example of an InSAR image of different ecosystems. The EcoSAR vegetation height measurements will provide similar, but higher resolution and higher accuracy tree height measurements than Shuttle Radar Topography Mission derived mean tree heights (Fatoyinbo et al, 2008). EcoSAR will also be able to measure permafrost depth and wetland extent.

The highly adaptable airborne EcoSAR system is critical for calibrating and validating the future DESDynI mission, as well as supporting science using existing and proposed international SAR missions such as the JAXA ALOS/PALSAR and the European Space Agency's BIOMASS mission.

2. Description of Proposed Technology

EcoSAR is a concept for a unique P-band Synthetic Aperture Radar instrument capable of providing unprecedented two- and three-dimensional measurements of ecosystem structure. The system will employ digital beamforming architecture, a highly capable digital waveform generator and receiver system, and advanced dual-polarization array antennas with an interferometric baseline of 25 m on the NASA P3 aircraft (see Fig. 1). The end result will be a first of its kind highly reconfigurable polarimetric and interferometric P-band SAR instrument deployable on a proven platform and capable to accurately characterize ecosystems and quantify biomass.

EcoSAR will leverage the L-band Digital beamforming SAR (DBSAR) architecture developed at Goddard Space Flight Center which demonstrated advanced digital beamforming SAR techniques for surface imaging and biomass applications (Rincon et al., 2010), state-of-the art antenna structure design development, and recent advances in digital waveform generation and data processing.

EcoSAR's digital beamforming allows considerable measurement flexibility through dynamic beam control design (Rincon, 2008A and 2008B). Some benefits in EcoSAR's digital beamforming include simultaneous measurement over both sides of the track, variable incidence angle, and ambiguity suppression. EcoSAR's digital beamforming will also enable the synthesis of multiple transmit and receive antenna beams simultaneously permitting the implementation of advanced imaging techniques.

EcoSAR will operate at a center frequency of 435 MHz (69 cm wavelength) and feature a fully programmable bandwidth. An operational mode with medium resolution (6 MHz -30 MHz) will be used as a nominal mode in frequency restricted areas, and a science mode with high resolution (up to 200 MHz) in authorized or remote areas.

Table 1: EcoSAR main characteristics

Center Frequency	435 MHz		Pulse Length	1 usec – 50 usec
Maximum Bandwidth	200 MHz		Array Peak Power	40 Watts
Polarization	Full		PRF	100 Hz – 10 KHz
Interferometric baseline	25 m		Swath	4 km *
Noise Equivalent σ^o	- 41 dB *		Finest Range Resolution	0.75 m
Total Number Channels	36		Single Look Azimuth Resolution	0.5 m

* from 8km altitude, 35 º incidence angle

This concept will also demonstrate a new standard for digital beamforming SAR systems with unmatched ranging performance, and mass and power attributes at least 10 percent lower than existing systems. The advanced EcoSAR architecture can provide unprecedented SAR and InSAR imaging resolutions (to 1m or finer). For instance, EcoSAR can support bandwidths up to 200 MHz, resulting in range resolutions at sub-meter scales ($>$ 0.75 m).

Table 2: The EcoSAR measurements will benefit Ecosystems and biomass research

Parameter	**EcoSAR**	**DBSAR**	**UAVSAR**
Bandwidth (MHz)	200	20	80
Range Resolution	0.75 m	7.5 m	1.88 m
NES0	-41 dB	- 40 dB	-53 dB
Single pass Interferometry	yes	no	no
Polarization	Full Quad	Full Compact	Full Quad
Hybrid Polarity	yes	no	no

EcoSAR concept is designed to fly on the NASA P3, which can accommodate other instruments, including DBSAR and a lidar. This arrangement sets the stage for a future single-aircraft DESDynI simulator/validator.

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