EcoSAR

P-band Digital Beamforming Polarimetric and Interferometric SAR instrument to measure Ecosystem Structure, Biomass and Surface Water

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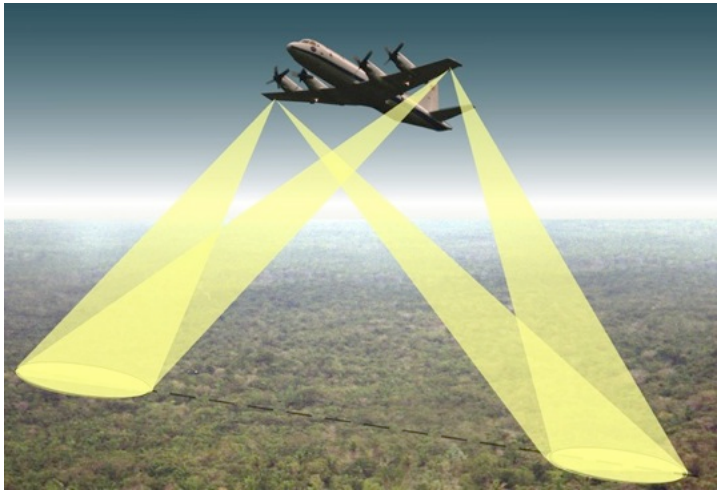


Introduction

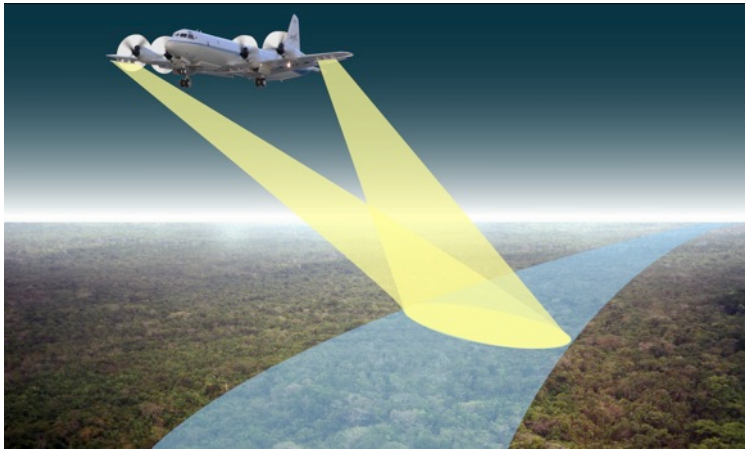
EcoSAR is a new airborne radar developed at NASA/Goddard Space Flight Center for the measurements of terrestrial ecosystem structure and biomass funded through the 2010 IIP:

- Acquires P-band InSAR measurements of vegetation structure and biomass in order to quantify carbon storage, sequestration and emissions in terrestrial vegetation.
- Employs Electronic Beam Steering and Digital Beamforming to implement Polarimetric and Interferometric Synthetic Aperture Radar (SAR).

EcoSAR onboard NOAA P3 aircraft during preparations for first test flight campaign. McDill Air Force Base, March 2014

EcoSAR System Overview

- Two polarimetric antenna arrays support single pass InSAR and Pol-InSAR.
- Beamforming architecture enables one-dimensional (across-track) scanning.
- Digital Arbitrary Waveform Generators determine beam steer and beam shape on transmit over a range of $\pm$ 45 degrees.
- Digital Beamforming synthesizes customized beams on receive.



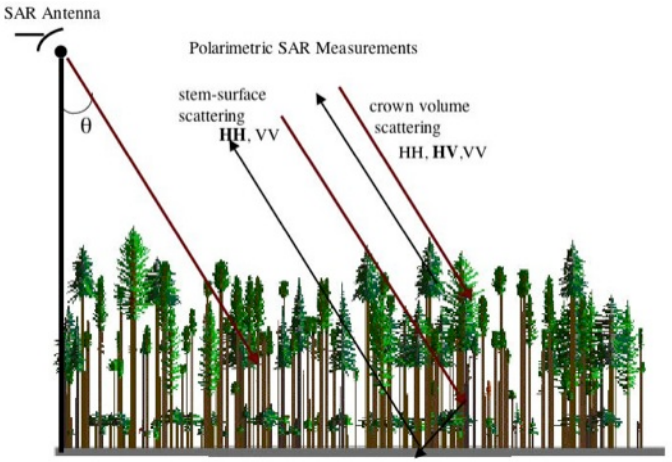
EcoSAR was designed to fly on a P3 aircraft.

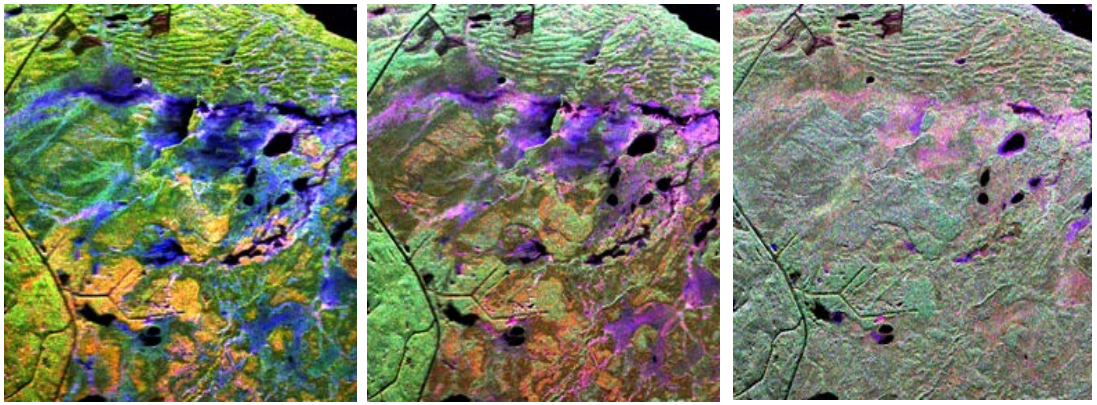
EcoSAR Main Characteristics

Center Frequency	435 MHz		Pulse Length	1 usec – 50 usec
Maximum Bandwidth	200 MHz		Array Peak Power	40 Watts
Polarization	HH, VV, VH,HV		PRF	100 Hz – 10 KHz
Polarization Isolation	> 30 dB		Swath	4 km – 8 km
Noise Equivalent σ^o	- 41 dB *		Finest Range Resolution	0.75 m
Total Number of active Channels	32		Single Look Azimuth Resolution	0.5 m
Interferometric baseline	25 m		Vertical Accuracy	~ 1 m

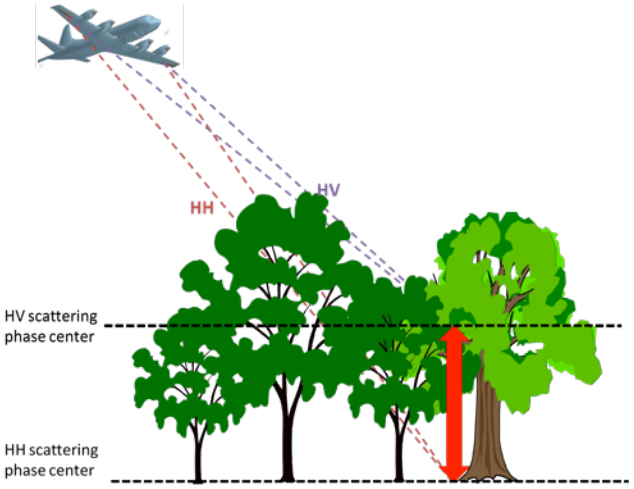
Instrument Science Rationale

- P-band SAR penetrates vegetation structure allowing the sensing of the entire canopy volume and woody density -> directly related to aboveground biomass.
- Polarimetric radar is sensitive to the shape, orientation and dielectric properties of scatterers -> allows identification and separation of the scattering mechanisms.
- InSAR is highly sensitive to the spatial variability of vertical structure parameters -> 3D height measurements
- Pol-InSAR provides measurements that will allow us to separate ground from canopy -> canopy height



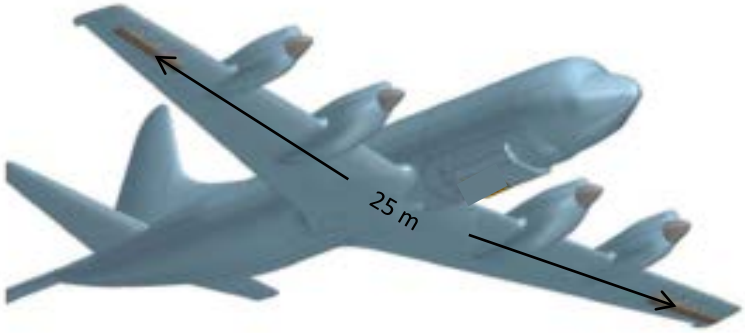


P-Band (HH,HV,VV) **L-Band (HH,HV,VV)** **C-Band (HH,HV,VV)**

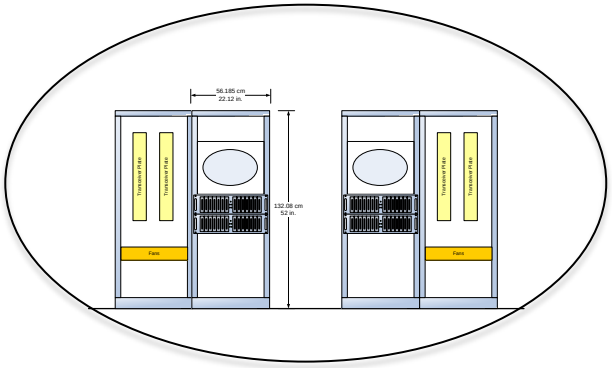


Summary of the EcoSAR Technology

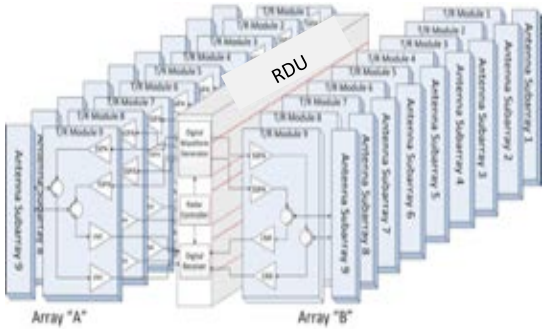
1) Antenna
   - Antenna Array
   - Antenna Fairing
2) Radar Electronics Unit
   - RF Transceivers
   - Power Distribution
   - Thermal System
3) Radar Digital Unit
   - Waveform generator
   - Data Acquisition
   - Processor
4) Computer System
   - Radar Control
   - Graphical Interface/Data Archiving
   - Inertial Motion Unit (IMU)/Avionics



Two array antennas separated by a 25 m baseline mount under the aircraft wings



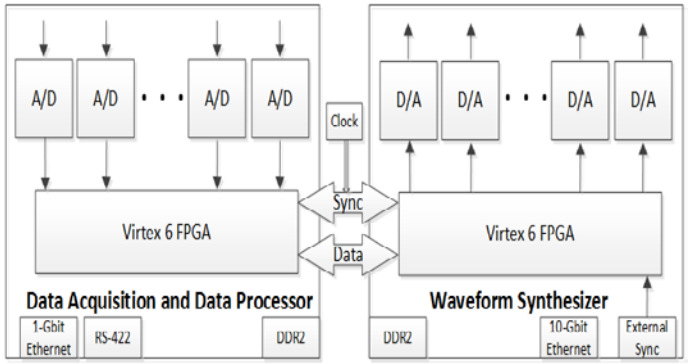
Radar transceivers, processor, power supplies, and cooling system reside in the fuselage.

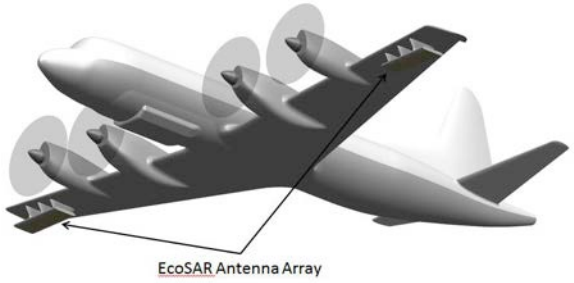


Multi-Channel Digital system generates TX signals and acquires return signals.

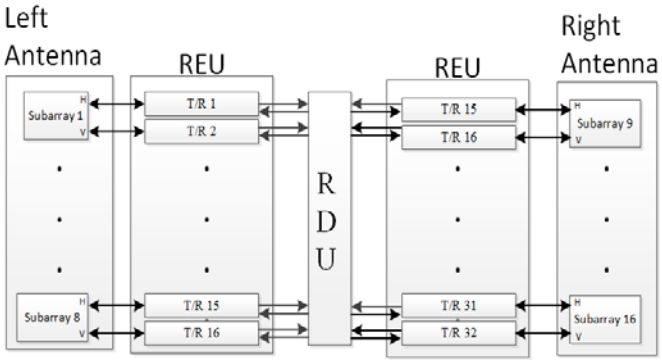
EcoSAR Architecture

- Radar Digital Unit (RDU) generates multiple independent waveforms with programmable phase and amplitude.
- RDU acquires and processes radar returns.
- Digital Beamforming is performed on board or off line.
- Multiple radar channels enable full polarimetry, standard and ping pong InSAR modes, and cross-track scanning over a wide range of angles.
- Two wing-mounted antenna arrays form a 25 m Interferometric baseline.
- 3 IMU systems measure acceleration, angular velocity, and position at the wings and fuselage.



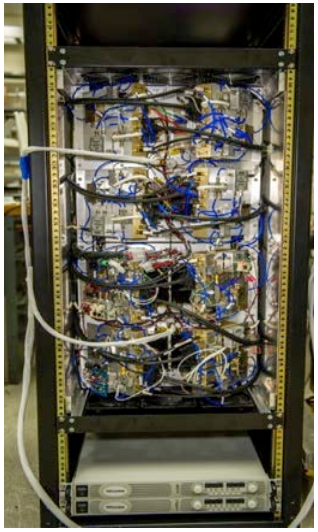


EcoSAR Antenna Configuration



EcoSAR Architecture

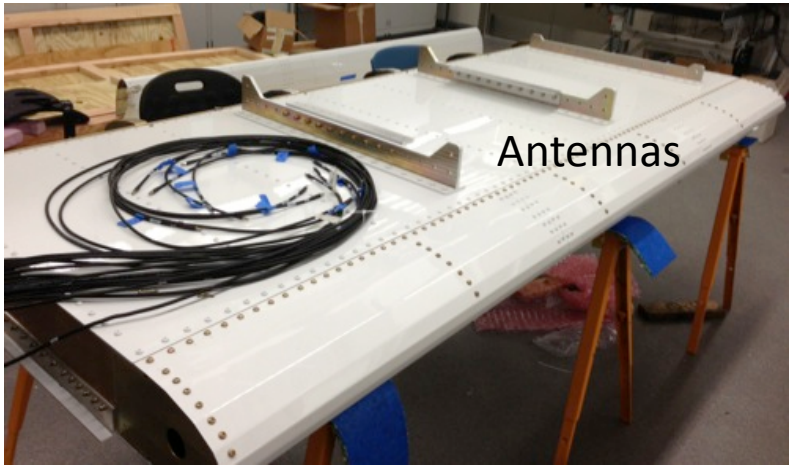
EcoSAR system



Transceiver

Processor

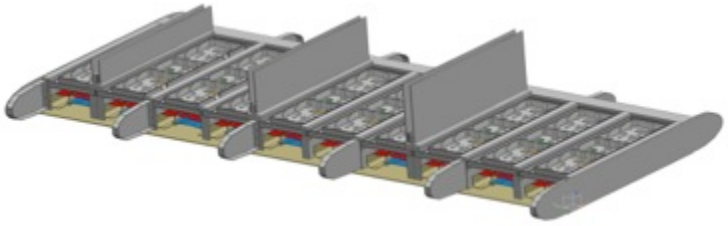
RAIDS



Antennas

- EcoSAR employs two antennas installed externally to the P3 aircraft under the wings.
- Each antenna is made up of 10 identical subarrays.
- The antenna elements required a custom (in-house) design to meet EcoSAR's bandwidth, polarization, and scan requirements.
- The element design adopted is based on stacked patch approach using a process of modeling, simulations, prototyping, and testing which led to the final element.

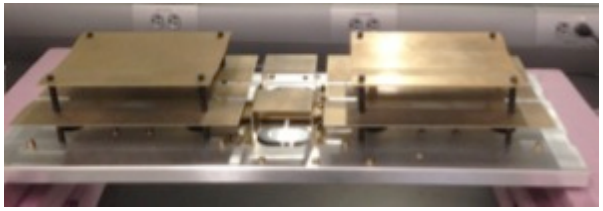
Antenna Configuration



Antenna Parameters

Type	Stacked Patch
Center Frequency	435 MHz
Max Bandwidth	200 MHz
Gain	19 dB
Polarization	Dual, linear
Scan angle	± 35 °
Cross Polarization Isolation	> 30 dB
Number of Sub Arrays	10
Total Number of Elements	20
Dimensions	3 m x 1 m

Antenna Subarray

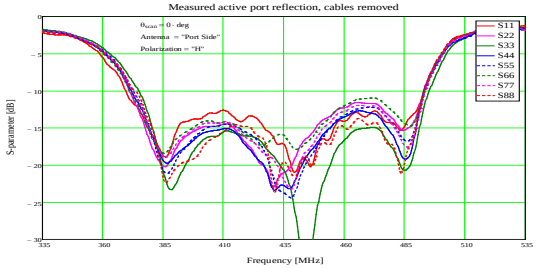


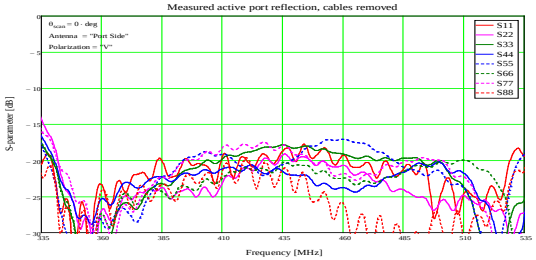
Antennas

- Met performance parameters of ± 35 ° scanning and greater than 30 dB cross-polarization isolation.
- The maximum bandwidth of 200 MHz was achieved at vertical polarization, and a narrower 120 MHz bandwidth at horizontal polarization.

Antenna Return Loss Measurements

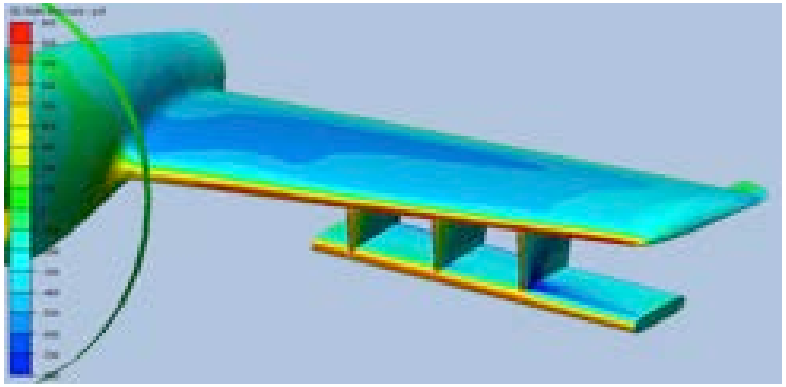
H POL





V POL

Pressure Distribution Analysis

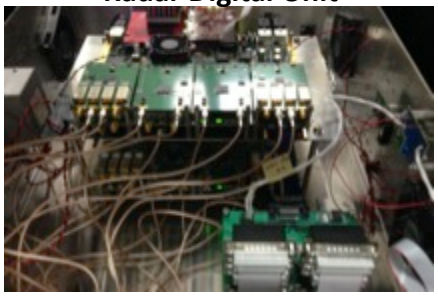


Antenna Installation

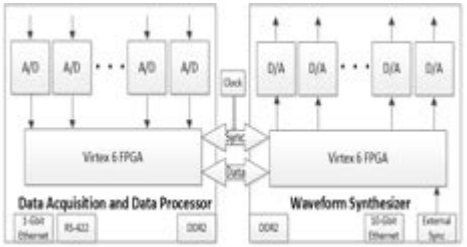
Radar Digital Unit (RDU)

- 32-channel arbitrary waveform synthesizer for transmit signals, 32-channel acquisition and onboard processor system for the return signals.
- Total of eight V6 FPGA-based mother boards, each board generates or acquires 8 independent waveforms.
- 32 waveform generators directly synthesize arbitrary P-band signals with up to 200 MHz bandwidth.
- 32 acquisition and processing channels sample the radar returns directly and implement onboard Digital I&Q demodulation, filtering.
- Fully programmable through Graphical Interfa Unit on host computer.
- 10 G-bit Ethernet data transfers to host computer\raid system.

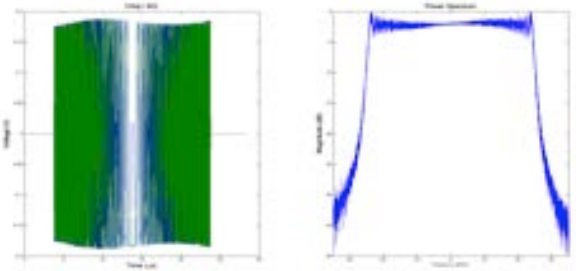
Radar Digital Unit



RDU Architecture



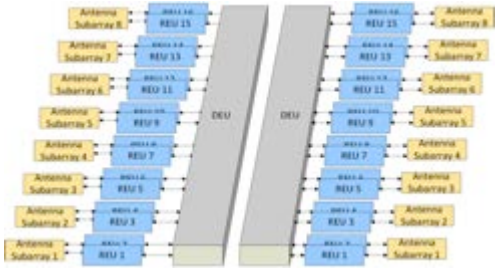
Loop Back Signal Measurements



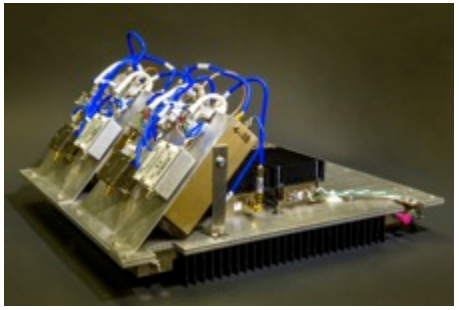
Radar Electronics Unit (REU)

- 32 transmit/receive (T/R) modules for the conditioning of the transmit and receive signals and for implementation of robust calibration schemes.
- In-house design based on a hybrid approach that employs connectorized RF components for the high power transmit sections and lower power printed circuit board (PCB) for the rest of the module.
- External contracts developed prototype circulators, switches and solid state power amplifiers (SSPA) with 200 MHz BW and 20 W power handling.
  - The amplifiers included fast turn on/off for reduction of power consumption and noise leakage.

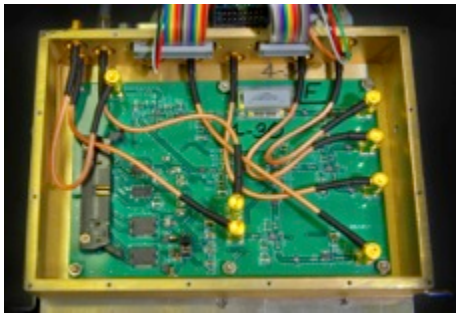
EcoSAR Architecture



T/R Module on thermal plate



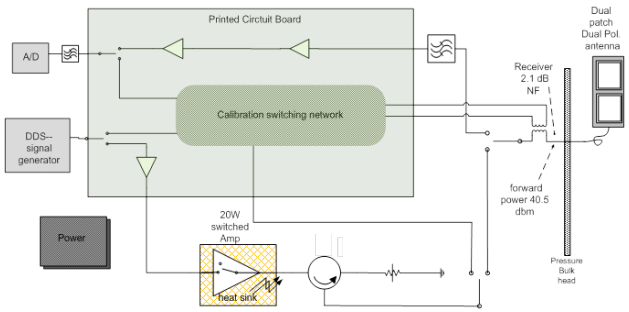
PCB section in enclosure



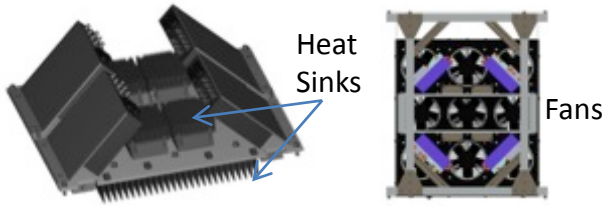
Radar Electronics Unit (REU)

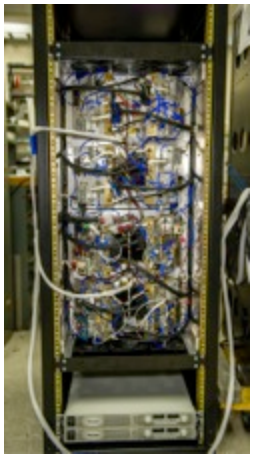
- The T/R modules are equipped with 20-Watt SSPA, low noise amplifiers (LNA), circulators, couplers, filters, and control switches.
- The power switching capability of the SSPA enable a relatively simple cooling system based on heat sinks and air cooling.
- Considerations for the mechanical design included physical mounting and vibration isolation, physical isolation of each channel for EMC/EMI purposes, heat dissipation from the power amplifier, physical access to facilitate interconnection, testing and maintenance.
- Final mechanical REU configuration employs NASA P3 aircraft racks.

Simplified transceiver Block Diagram



Simplify Thermal Approach

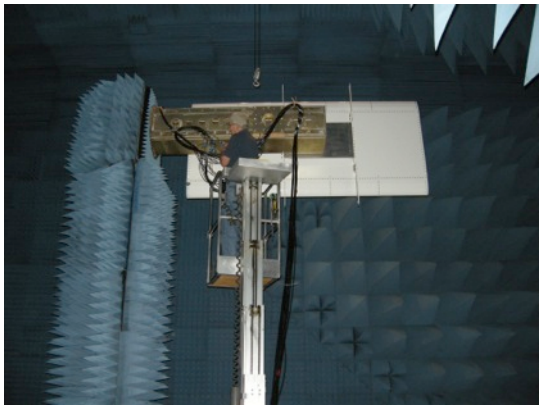




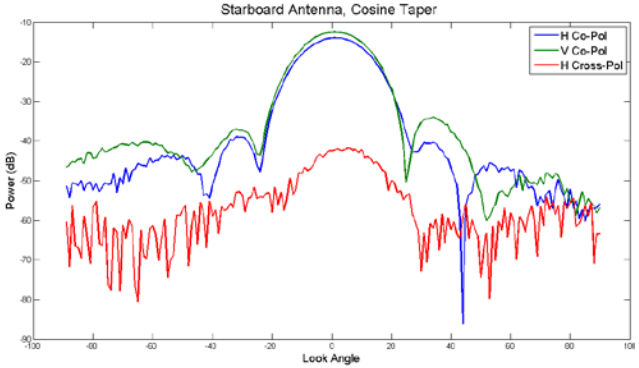
Integrated rack of 16 transceivers.

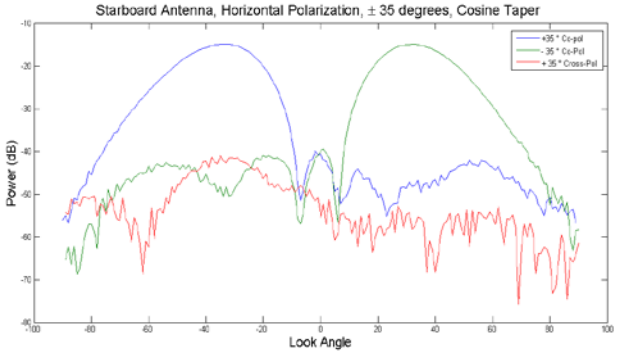
Anechoic Chamber Calibration

- The full system was operated in a low frequency anechoic chamber in transmit and receive modes.
- Beam steering weights were derived from the characterization of each radar transmitter and receiver channel (amplitude and phase).
- Transmit and receive far-field patterns were measured for several steering look angle and amplitude taper weights.

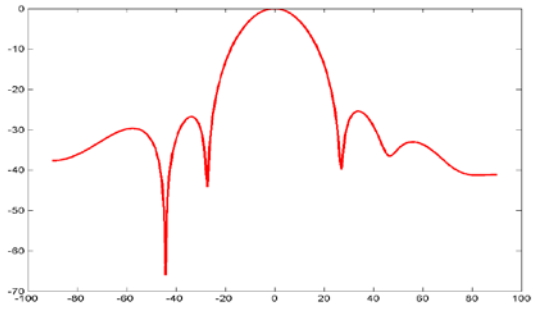


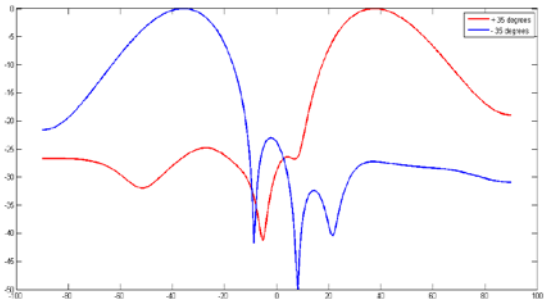
Anechoic Chamber Antenna Installation





Active transmit pattern measurements with cosine taper: boresight (left), - 35° Look Angle (right blue), + 35° (right green, and cross pol (right red).





Active receive pattern measurements with cosine taper: boresight (left), and - 35° Look Angle (right).

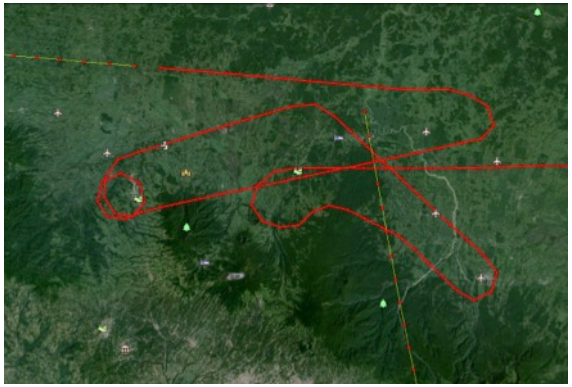
Anechoic Chamber REU and RDU configuration

Flight Campaign

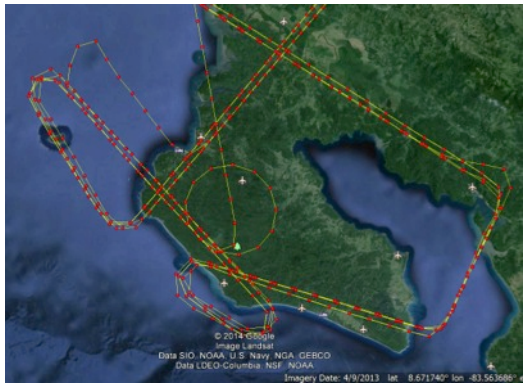
- EcoSAR first test flights and a science campaign were conducted onboard a NOAA P3 aircraft in March 2014.
- The areas measured with the radar included sections of Andros Island in the Bahamas, and the La Selva and Corcovado National parks in Costa Rica.
- Field measurements over these areas were also conducted during the same month.

Andros Island, Bahamas

EcoSAR onboard NOAA P3 during First Flight , March 27, 2014

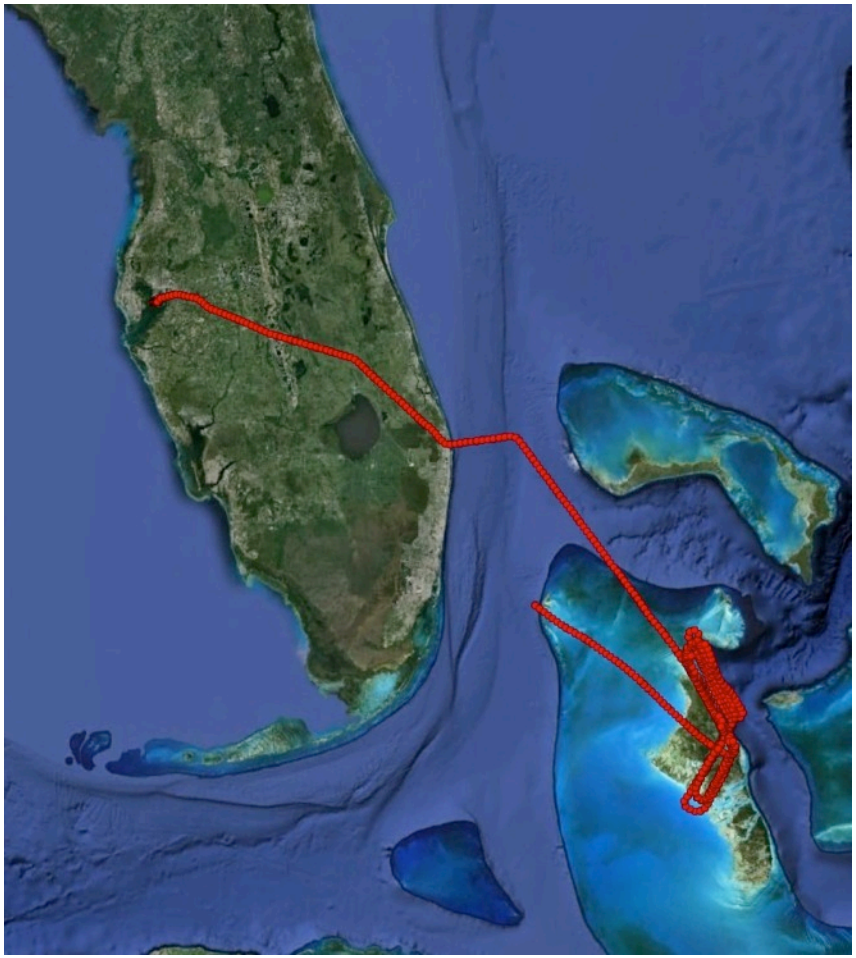


La Selva National Park, Costa Rica

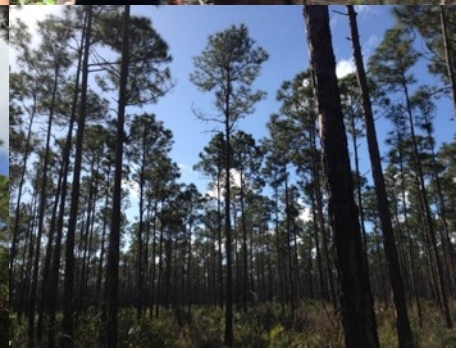


Corcovados National Park, Costa Rica

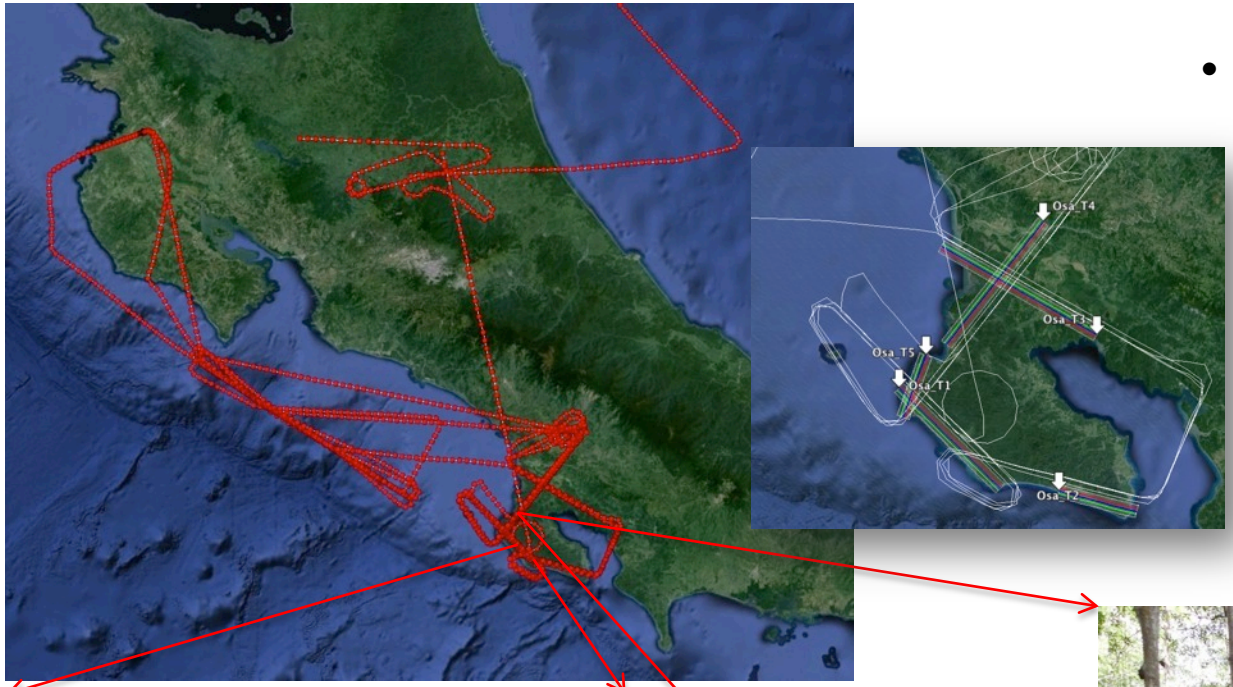
March 27 Test Flight: Andros Island



- Engineering Check Flight: 1 hour flight from MacDill AFB
- Full 200 MHz frequency authorization at P-band
- Most forested Island in the Bahamas
- Calibration site
- Field Measurements



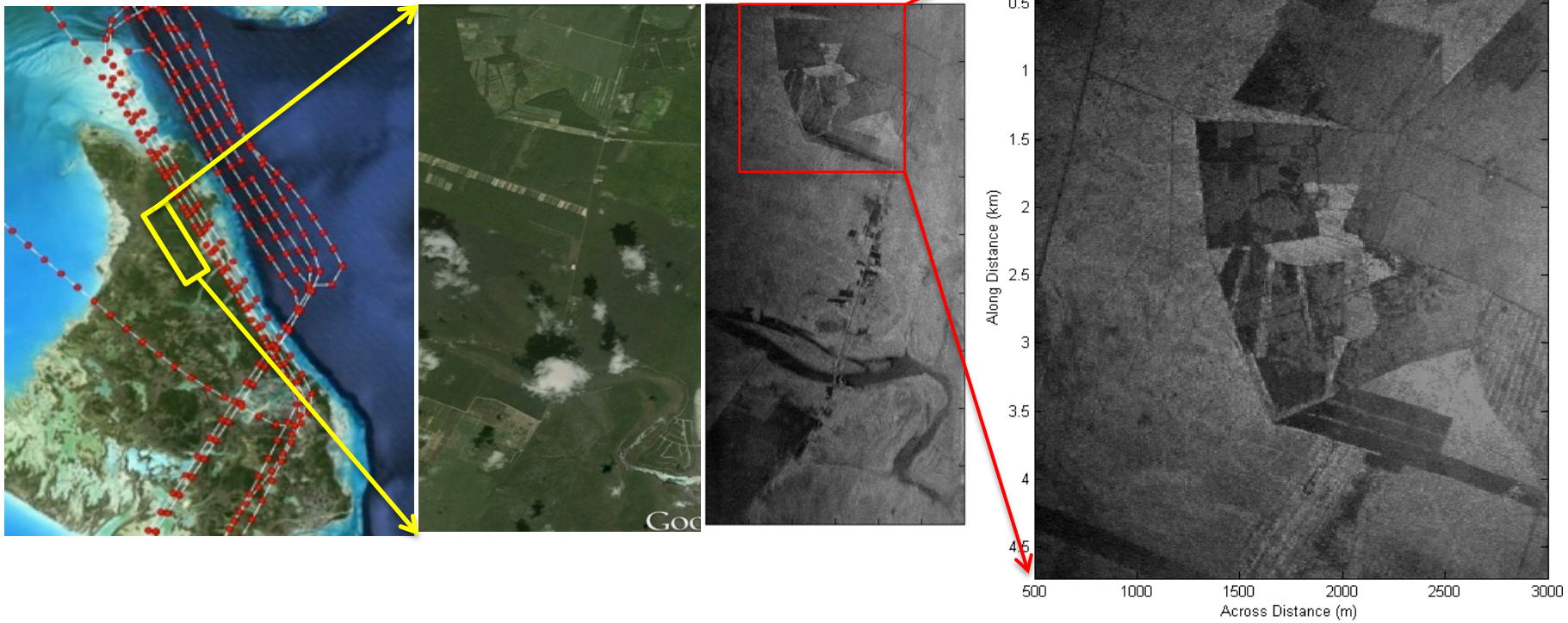
March 29-31 Science Flights to Costa Rica



- 3 Sites:
  - La Selva
  - Terraba Sierpe Mangroves
  - Corcovado National Park

First EcoSAR Images

Google Images of Andros Island



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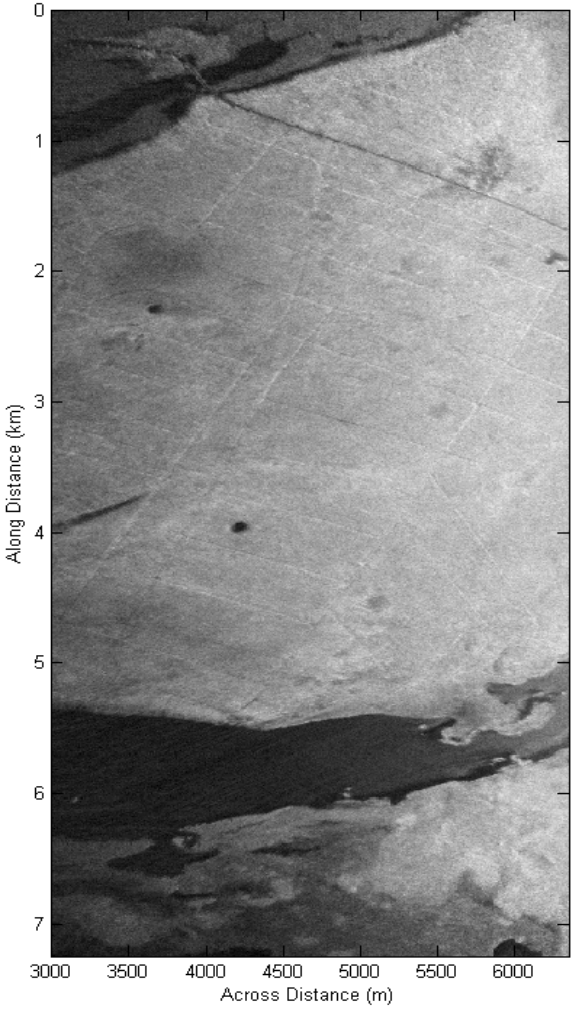
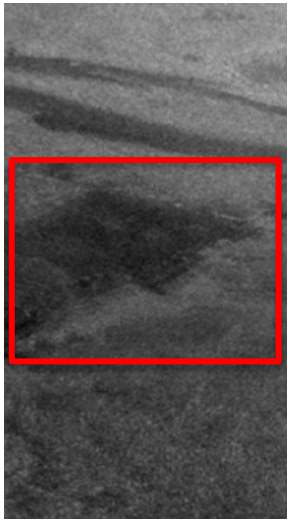
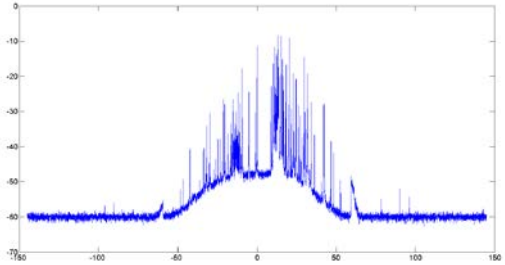


RFI Measurements

- RFI measurements were acquired at each location in sniffing mode.
- The RFI present during the EcoSAR measurements affects image focusing and reduces image quality.
- Despite the on board filtering and large coherent signal-processing gain of the SAR processing, RFI remains in the focused image.
- Working on the development of robust RFI detection and removal.

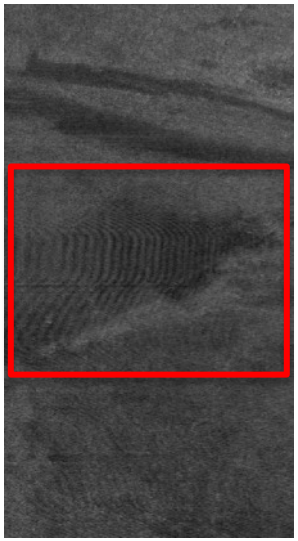
Spectrum with onboard 50 MHZ Digital Filter

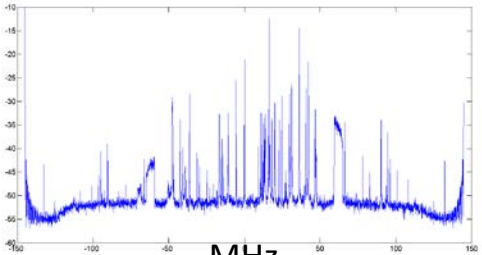




MHz

Spectrum without onboard Digital Filtering





MHz

Concluding Remarks and Future Plans

- The EcoSAR three year IIP development was successful in designing, fabricating and testing the instrument.
- The instrument's first flight campaign was successfully accomplished, generating a large data sets for algorithm development and system performance assessment.
- Current work is focused on RFI removal and robust wide band Beamforming.
- EcoSAR will also serve as a test bed to study advanced beamforming techniques, which will include adaptive waveform generation, orthogonal waveform operation.
- Website- coming soon! www.ecosar.gsfc.nasa.gov

Goddard
SPACE FLIGHT CENTER

NASA

Thank you!

Mission Context

- Global Ecosystem Dynamics Initiative (GEDI)
  - NASA Lidar to be launched in 2019 on ISS
- Biomass (ESA Earth Explorer Mission):
  - P-band (435 MHz); fully polarimetric; Digital Beamforming
  - Launch around 2020
- NI-SAR (NASA JPL-ISRO)
  - L- and S-band; Digital Beamforming (SweepSAR)
  - Launch (2020)
- TanDEM-L (DLR and JAXA)
  - L-band, Interferometric, 2 spacecraft system, Digital Beamforming,
  - Launch 2019 (TBD)