Radar-based estimates of biomass

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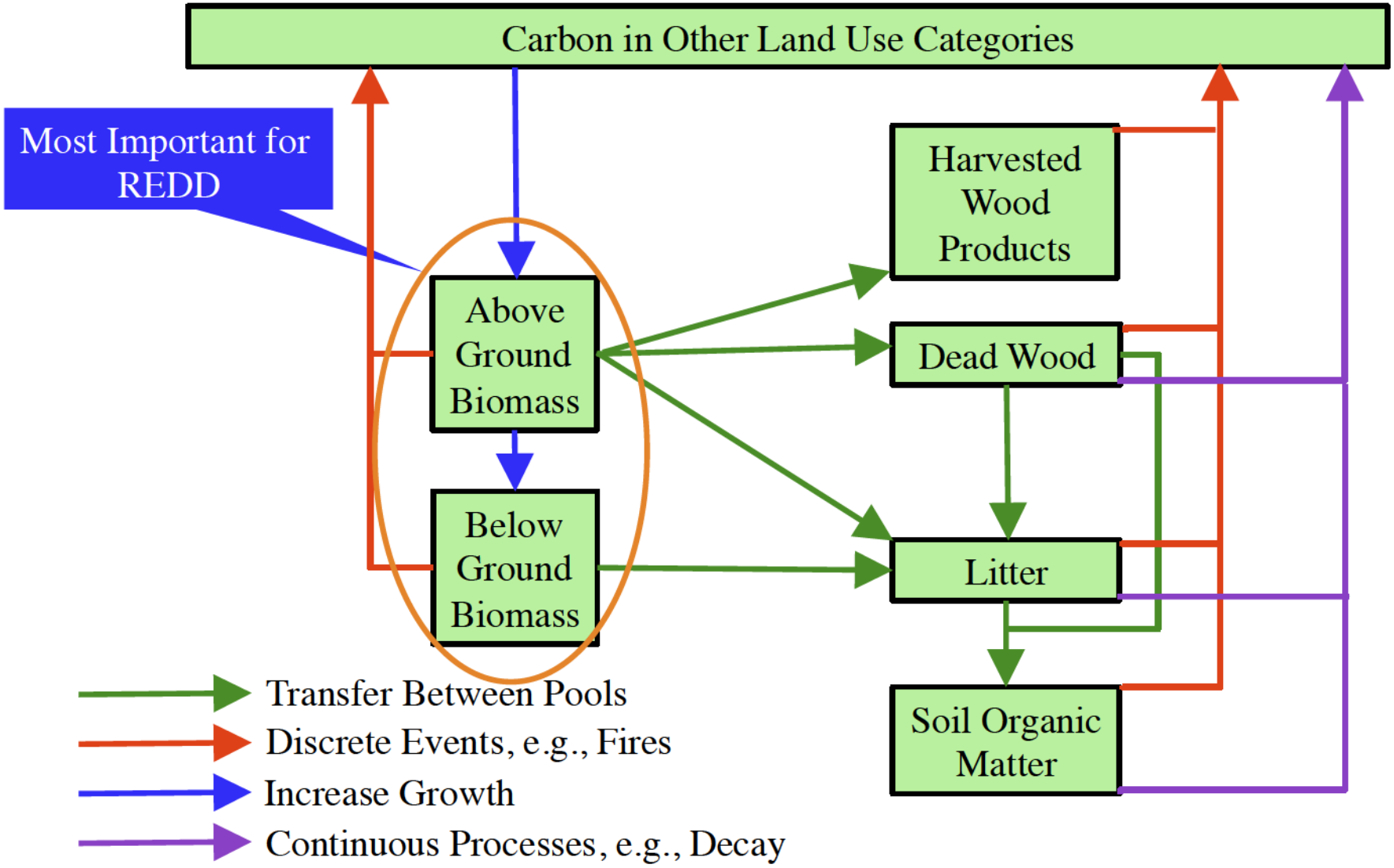
REDD Vegetation Carbon Pools



REDD Monitoring

- Currently planned methodologies* for REDD monitoring and verification are shown in the figure below.
  - Resolutions range from < 5m to the 1 km scale corresponding scales for resolving change.
  - Note, the lack of radar data sets in the proposed monitoring schemes.
- There is a good potential for use of airborne radar remote sensing to meeting REDD+ objectives.

Sensor & resolution	Examples of current sensors	Minimum mapping unit (change)	Cost	Utility for monitoring	
Coarse (250-1000 m)	SPOT-VGT (1998-) Terra-MODIS (2000-) Envisat-MERIS (2004 -)	~ 100 ha ~ 10-20 ha	Low or free	Consistent pan-tropical annual monitoring to identify large clearings and locate "hotspots" for further analysis with mid resolution	Hotspot monitoring
Medium (10-60 m)	Landsat TM or ETM+, Terra-ASTER IRS AWiFs or LISS III CBERS HRCCD DMC SPOT HRV	0.5 - 5 ha	Landsat & CBERS will be free from 2009 <$0.001/km² for historical data $0.02/km² to $0.5/km2 for recent data	Primary tool to map deforestation and estimate area change	Primary RS tool
Fine (<5 m)	IKONOS QuickBird Aerial photos	< 0.1 ha	High to very high $2 -30 /km²	Validation of results from coarser resolution analysis, and training of algorithms	Validation

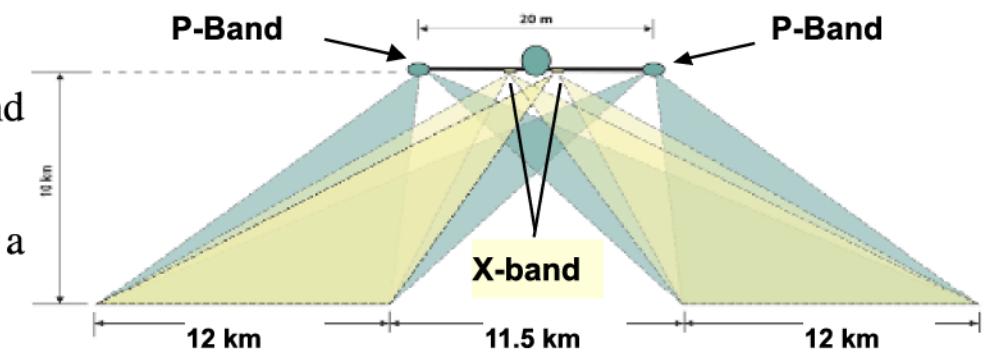
Source: GOFC-GOLD REDD Source book

*Nalin Sirvastava, *IPCC Guidelines and REDD Monitoring and Verification, Rome, Nov. 2010*

GeoSAR

- Developed (and supported) by NASA's JPL for wide-area, airborne mapping applications.
- Operated commercially by EarthData (now Fugro-EarthData) since 2002.
- Up to 12000 m with an airspeed of over 200 m/s.
- Collects X-Band VV and P-Band HH interferometrically and P-band HV.
- High-accuracy, digital elevation models (DEMs), and ortho-mosaics from both X-band (DSM) and P-band (DTM).

- GeoSAR transmits at X-band between 9.63GHz and 9.79GHz
- The P-band SAR operates between 270 Hz and 430 MHz
- Bandwidth of 160 MHz (both bands) yields a best slant-range resolution of ~1m
- Single-pass interferometry is achieved using horizontal baselines of 2.6 m at X-band and 20 m at P-band.

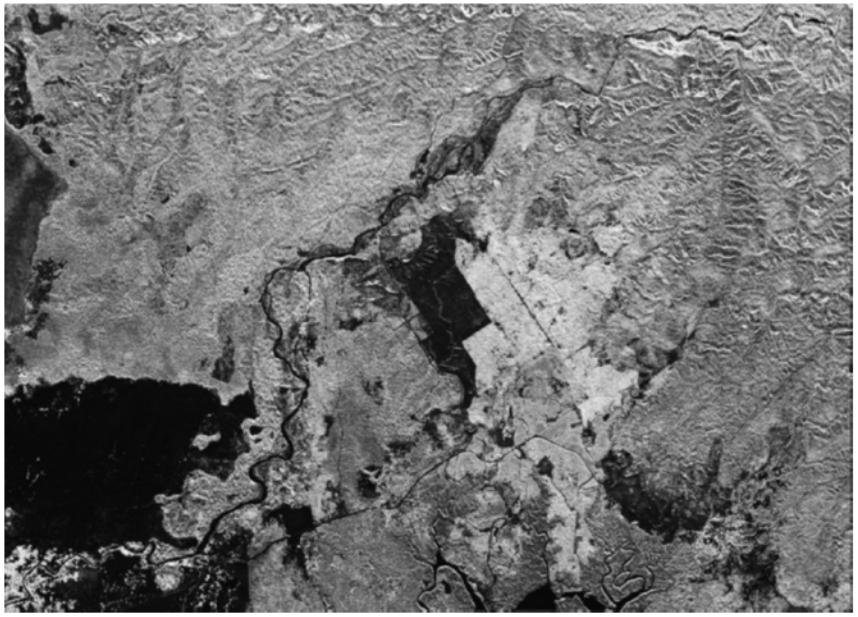


Collection Height: 10,000 -12,500m (32,000 to 41,500 ft)

GeoSAR Specifications

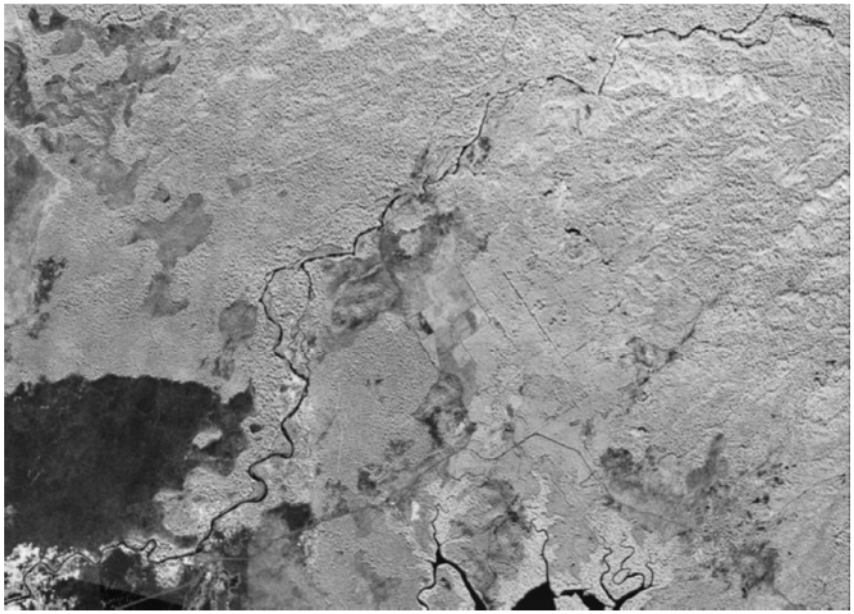
P-BAND

Peak Transmit Power 4 kW	
Bandwidth	80/160 MHz
Pulse Length	40 ms
Sampling	8/4 BFPQ@160 MHz 8 Bit @80 MHz
Antenna Size	1.524 m x .381 m
Antenna Gain at Boresight	11 dBi
Look Angle Range	22°-60°
Wavelength	.86 m (160 MHz) .96 m (80 MHz)
Center Frequency	350 MHz
Baseline Length	20 m and 40 m
Baseline Tilt Angle	0°
Platform Altitude	5000 m -12000 m

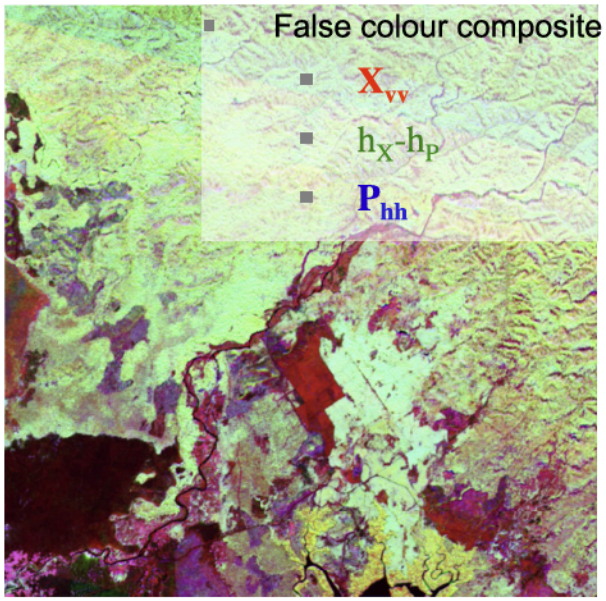


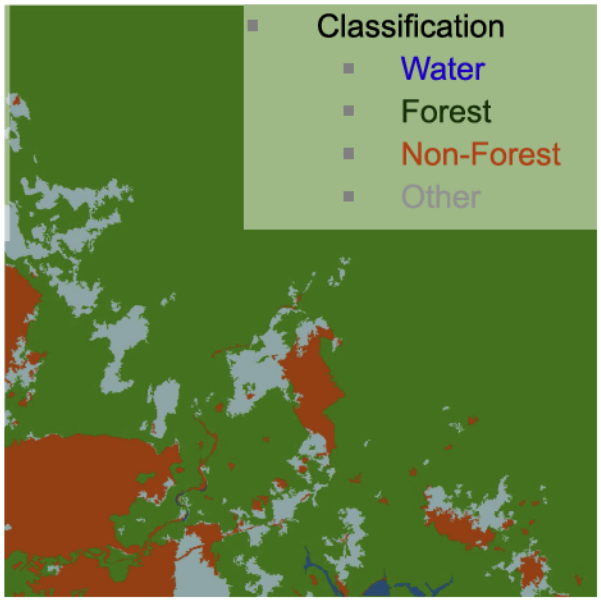
X-BAND

Peak Transmit Power 8 kW	
Bandwidth	80/160 MHz
Pulse Length	40 ms
Sampling	8/4 BFPQ @160 MHz 8 Bit @80 MHz
Antenna Size	1.5 m x .035 m
Antenna Gain at Boresight	26.5 dBi
Look Angle Range	22°-60°
Wavelength	.031m (160 MHz) .031 m (80 MHz)
Center Frequency	9.755 MHz
Baseline Length	2.6 m or 5.2 m
Baseline Tilt Angle	0°
Platform Altitude	5000 m -12000 m

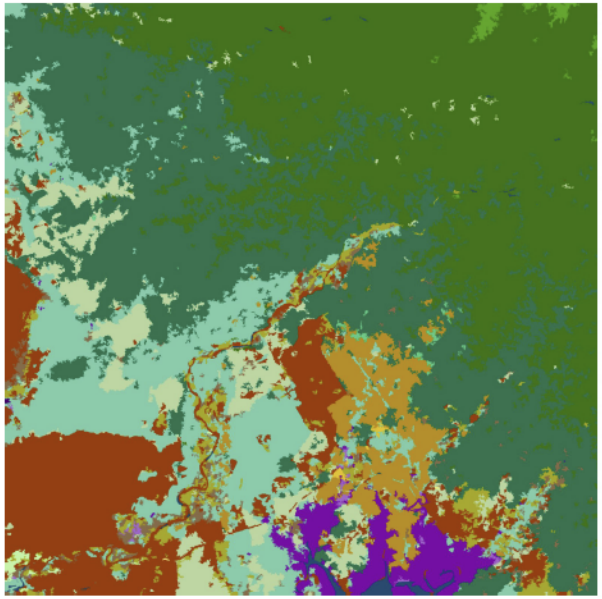


GeoSAR 2006 Classification





15.8km



- Water
- Lowland Primary Forest
- Lower Montane Primary Forest
- Mid-Montane Primary Forest
- Upper Montane Primary Forest
- Lowland Secondary Forest
- Lower Montane Secondary Forest
- Lowland Eucalypt Savannah
- Other Forest (south)
- Mangrove (short)
- Mangrove (Tall)
- Mangrove (Other)
- Bare Soil / Grass
- Scrub
- Scrub
- Scrub
- Alpine Grass
- Alpine Scrub
- Rubber (Young)
- Rubber (Mature)
- Teak
- Oil Palm (Young)
- Oil Palm (Mature)
- Coconut
- Garden
- Urban
- Other Forest (north)

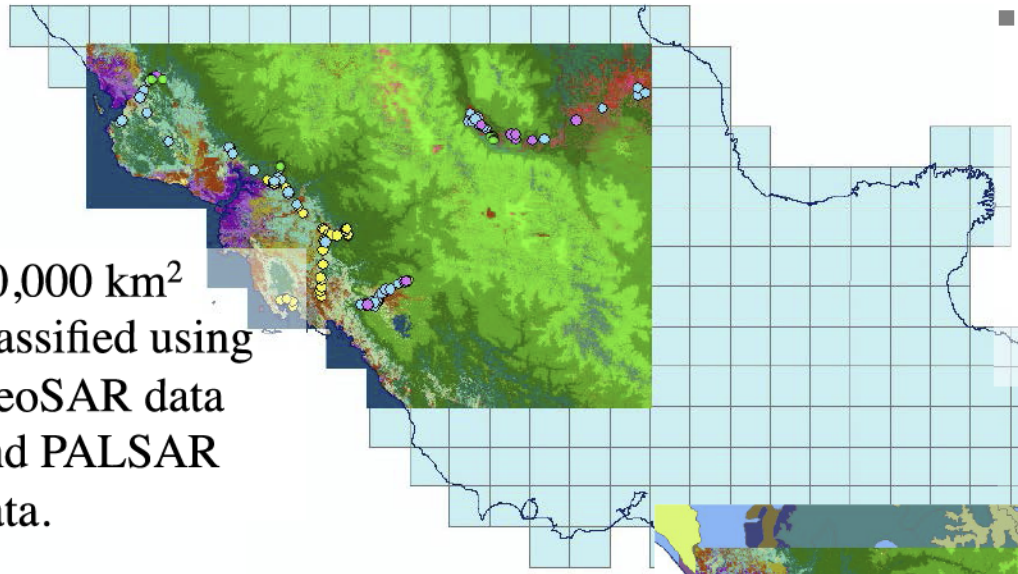
- Lower left: ~0.25ha segmentation, 27 classes, overall accuracy >90%.
- Left, reduced class set, ~1ha segmentation, $P_{ff} > 0.99$, $P_{nn} > 0.95$.
- Corresponding to potential bias of ~2% and uncertainty in AGLB *change* due to

  $O_{F \rightarrow N}$

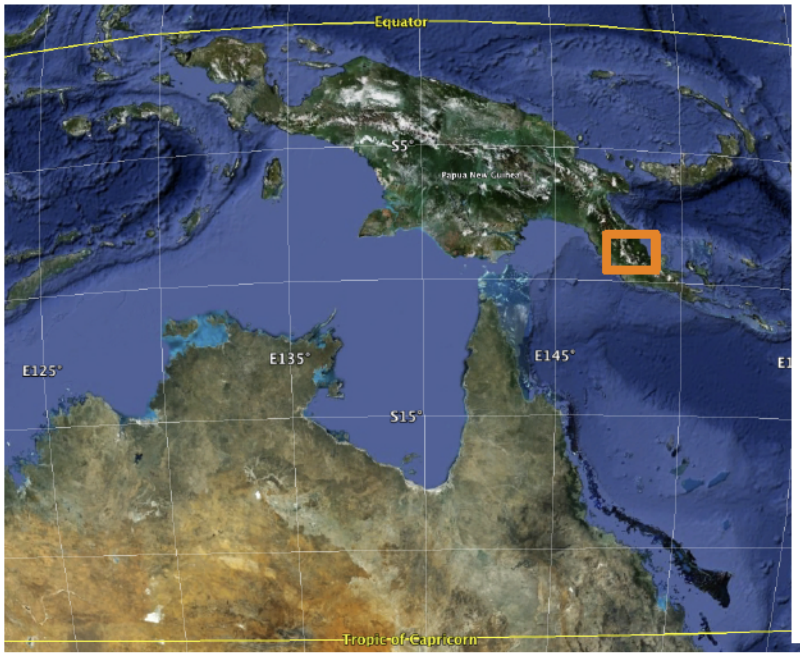
  of ~12%
- Note that overall uncertainty in estimate of AGLB change depends upon prevalence of change types.
- GeoSAR availability limited temporally, so compare with satellite system, PALSAR FBD L1.1 LHH/LHV + GeoSAR DTM information

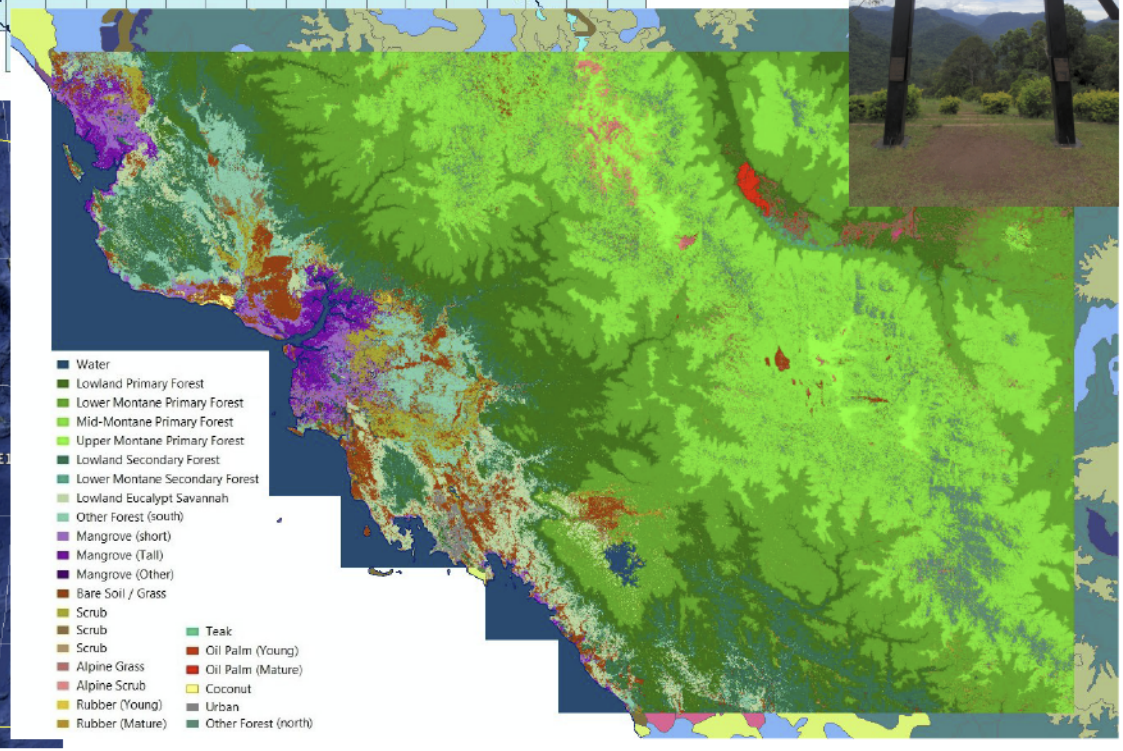
Papua New Guinea Study Region

- 20,000 km^2 classified using GeoSAR data and PALSAR data.



- Examples taken from the Kokoda Track and Owen Stanley Ranges Remote Sensing Project, an initiative of the Department of Environment and Conservation of PNG, in collaboration with the Australian Govt.

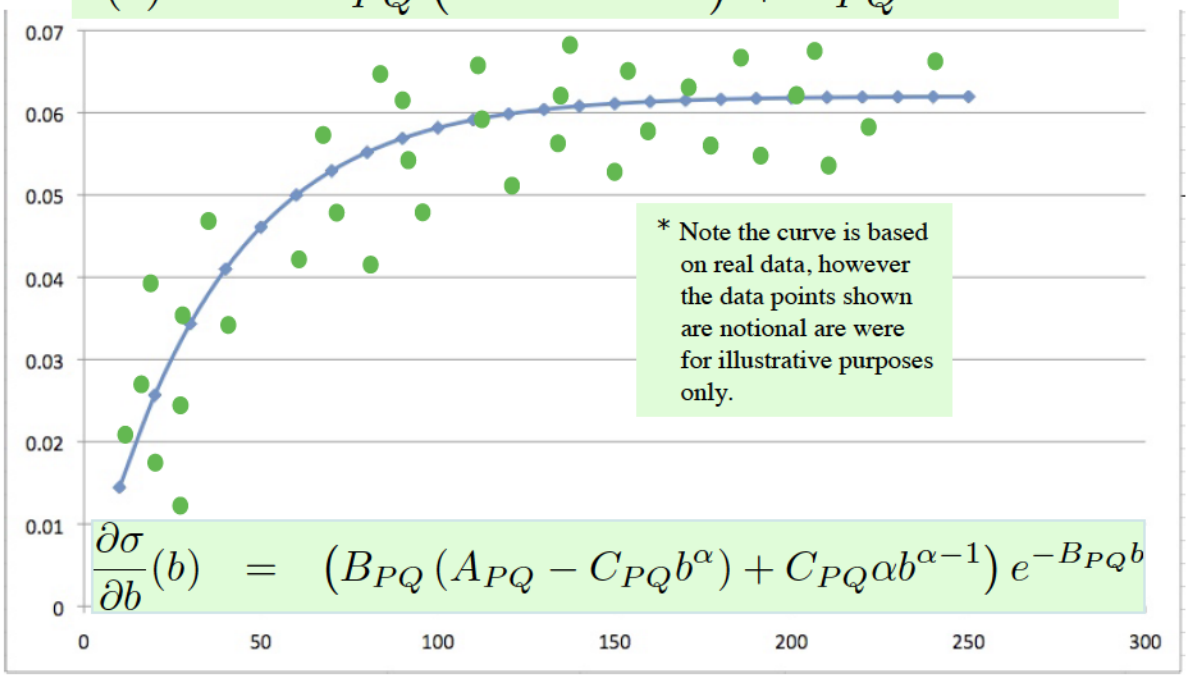




Backscatter to Biomass Relationship

- To get the biomass sensitivity with respect to radar σ_o measurements fit(s) to a physically based model function (see below) are made from which the derivatives can be computed.
  - It is assumed that the data used to make the fit(s) encompass data collected from multiple sensors, multiple seasons, different weather conditions, different incidence angles (albeit within the optimal range of 30-40°) such that that our fit accurately reflects the mean of radar backscatter measurements as a function of the biomass, another words, i.e., it is assumed the fit is perfect for the mean and this same fit to the mean will remain true independent of the sensor or range of conditions used to make the measurements.
  - *Since the derivative can be very sensitive to the fit, particularly for the higher biomass level where the signal tends to saturate, different fit functions a methods are being considered.*

$$\sigma(b) = A_{PQ}\left(1 - e^{-B_{PQ}b}\right) + C_{PQ}b^{\alpha}e^{-B_{PQ}b}$$



$$\frac{\partial\sigma}{\partial b}(b) = \left(B_{PQ}\left(A_{PQ} - C_{PQ}b^{\alpha}\right) + C_{PQ}\alpha b^{\alpha-1}\right)e^{-B_{PQ}b}$$

An implicit assumption is being made of no incidence angle variation to the backscatter for a given biomass level in the specified range of incidence angles.

Basic Equation for Biomass Estimation Accuracy

- The biomass estimation error, Δb, is roughly given by

$$\Delta b = \left(\left[\begin{array}{ccc} \frac{\partial b}{\partial \sigma_{hh}} \Delta\sigma_{hh} & \frac{\partial b}{\partial \sigma_{hv}} \Delta\sigma_{hv} & \frac{\partial b}{\partial \sigma_{vv}} \Delta\sigma_{vv} \end{array} \right] P_{cal}^{t} \Gamma P_{cal} \left[\begin{array}{c} \frac{\partial b}{\partial \sigma_{hh}} \Delta\sigma_{hh} \\ \frac{\partial b}{\partial \sigma_{hv}} \Delta\sigma_{hv} \\ \frac{\partial b}{\partial \sigma_{vv}} \Delta\sigma_{vv} \end{array} \right] \right)^{\frac{1}{2}}$$

where σ_{hh}, σ_{hv}, σ_{vv} are the measured polarimetric σ_o measurements, P_{cal}, is a polarimetric calibration matrix and Γ is the polarimetric correlation matrix which is a measure of how correlated the measurements are between the various polarizations given by

$$P_{cal} = I + Q = I + \left[\begin{array}{ccc} 0 & \delta_{12} & \delta_{13} \\ \delta_{21} & 0 & \delta_{23} \\ \delta_{31} & \delta_{32} & 0 \end{array} \right] \qquad \Gamma = \frac{1}{N_p^2} \left[\begin{array}{ccc} \epsilon_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \epsilon_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \epsilon_{33} \end{array} \right]$$

where N_p is the number of polarimetric observations (1, 2 or 3) are ε_{ii} is 1 or 0 depending on whether the observation is present, and the γ_{ij} is the correlation between the ith and j^{th} polarimetric channels

Error in σ_o Measurements

- The error in the backscatter measurements, $\Delta\sigma_{pq}$ (pq=hh,hv,vv), are a function of speckle, thermal noise, temporal variability of the backscatter, calibration errors (which in turn depend on pointing DEM errors) and area projection correction terms as given by the following equation.

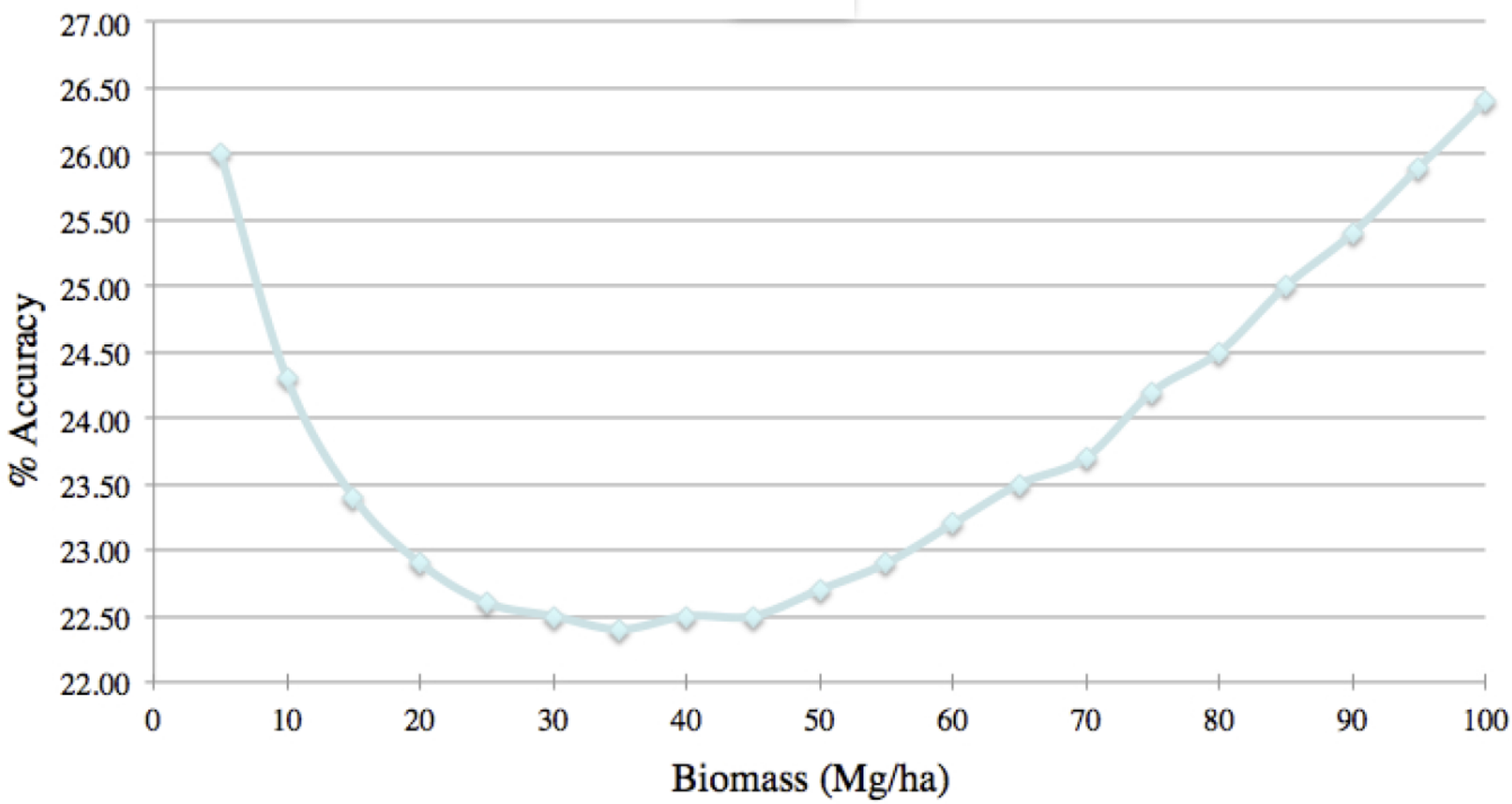
$$\Delta\sigma_{pq} = \left[\left(\overbrace{\frac{1}{\sqrt{N}}\frac{1}{\sqrt{N_{o_s}}}}^{\text{Speckle Noise}} + \overbrace{\frac{1}{\sqrt{N}}\frac{1}{\sqrt{N_{o_t}}}\frac{1}{SNR}}^{\text{Thermal Noise}}\right)\sigma_{pq} + \overbrace{\frac{1}{\sqrt{N_{o_t}}}\Delta\sigma_{pq_t}(b)}^{\text{Backscatter Temporal Variability}} + \overbrace{\frac{1}{\sqrt{N_{o_t}}}\Delta\sigma_c}^{\text{Calibration Errors}} + \overbrace{\sqrt{\frac{A_{dem}}{A_{pix}}}\frac{1}{\sqrt{N}}\frac{1}{\sqrt{N_{o_s}}}\Delta\sigma_a}^{\text{Area Projection Errors}}\right]$$

Symbol	Definition
N	Number of spatial looks per observation.
N_{ot}	Total number of observations.
N_{os}	Observations with non-correlated speckle
N_{oi}	Observations with correlated speckle
SNR	Signal-to-Noise Ratio
$\Delta\sigma_{pqt}$	Backscatter temporal variability
$\Delta\sigma_c$	Backscatter calibration error
$\Delta\sigma_a$	Backscatter area projection error
A_{dem}	Area of a pixel in DEM used for slope computations
A_{pix}	Area in a radar pixel

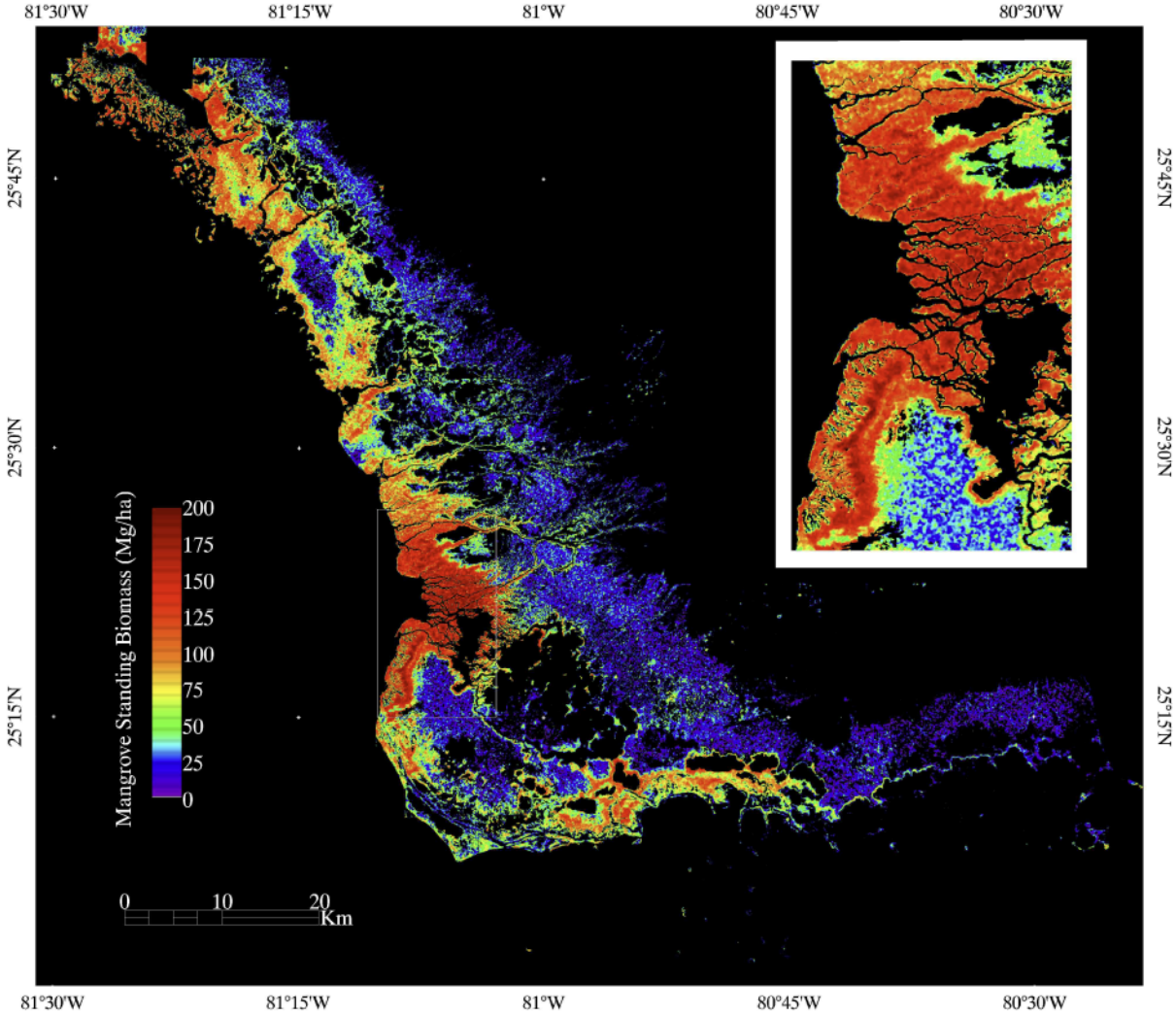
$$N_{o_t} = N_{o_s} + N_{o_i}$$

UAVSAR L-band Example

- Estimated biomass estimation accuracy for low biomass regions (< 100 Mg/ha) for one hectare size cells using the UAVSAR radar.
  - Assumed temporal backscatter variability of 0.5 dB measured at La Selva, Costa Rica.

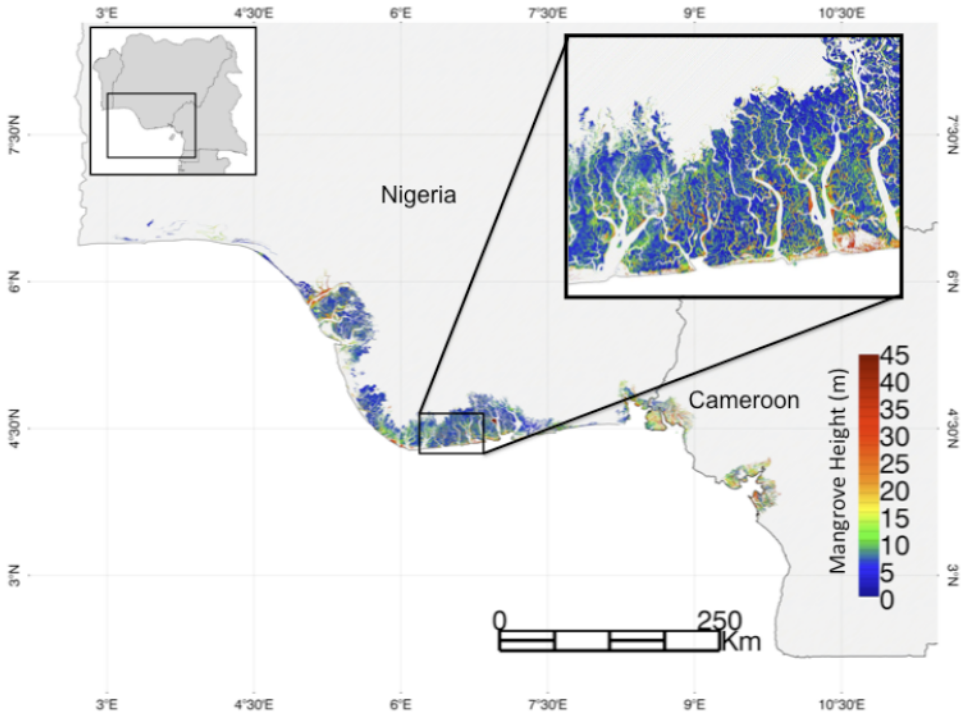


Mapping Biomass of Mangrove Forest in the Everglades National Park (ENP) using SRTM



Marc Simard et al., "Mapping Height and Biomass of Mangrove Forests in Everglades National Park with SRTM Elevation Data", *Photogrammetric Engineering and Remote Sensing*, SRTM special issue, April 2006

Height and Biomass Map of All Mangrove Forests of Africa



Fatoyinbo & Simard, IJRSE 2012

Country	Area in km^2	Total Biomass in Mg	Mean Biomass in Mg/ha
Angola	154	1,441,200	93
Benin	18	137,719	76
Cameroon	1,483	25,334,900	171
Congo	15	267,603	178
Cote d'Ivoire	32	406,516	124
Djibouti	17	1,653,170	90
DRC	183	51,570	140
Egypt	1	8,344	117
Equatorial Guinee	181	2,922,420	161
Eritrea	49	640,038	129
Gabon	1,457	23,840,000	162
Gambia	519.11	5,509,300	106
Ghana	76	742,925	97
Guinea	1,889	18,153,800	108
Guinea Bissao	2,806	31,712,300	113
Kenya	192	2,294,820	119
Liberia	189	2,141,860	113
Madagascar	2,059	24,856,900	121
Mauritania	0.4	4,156	95
Mozambique	3,054	30,974,100	101
Nigeria	8,573	94,788,000	111
Senegal	1,200	11,462,100	95
Sierra Leone	955	10,655,600	112
Somalia	30	436,907	143
Soudan	4	135,626	113
South Africa	12	40,018	100
Togo	2	15,861	78
Tanzania	809	11,037,800	136
Africa	25,960	301,665,553	116

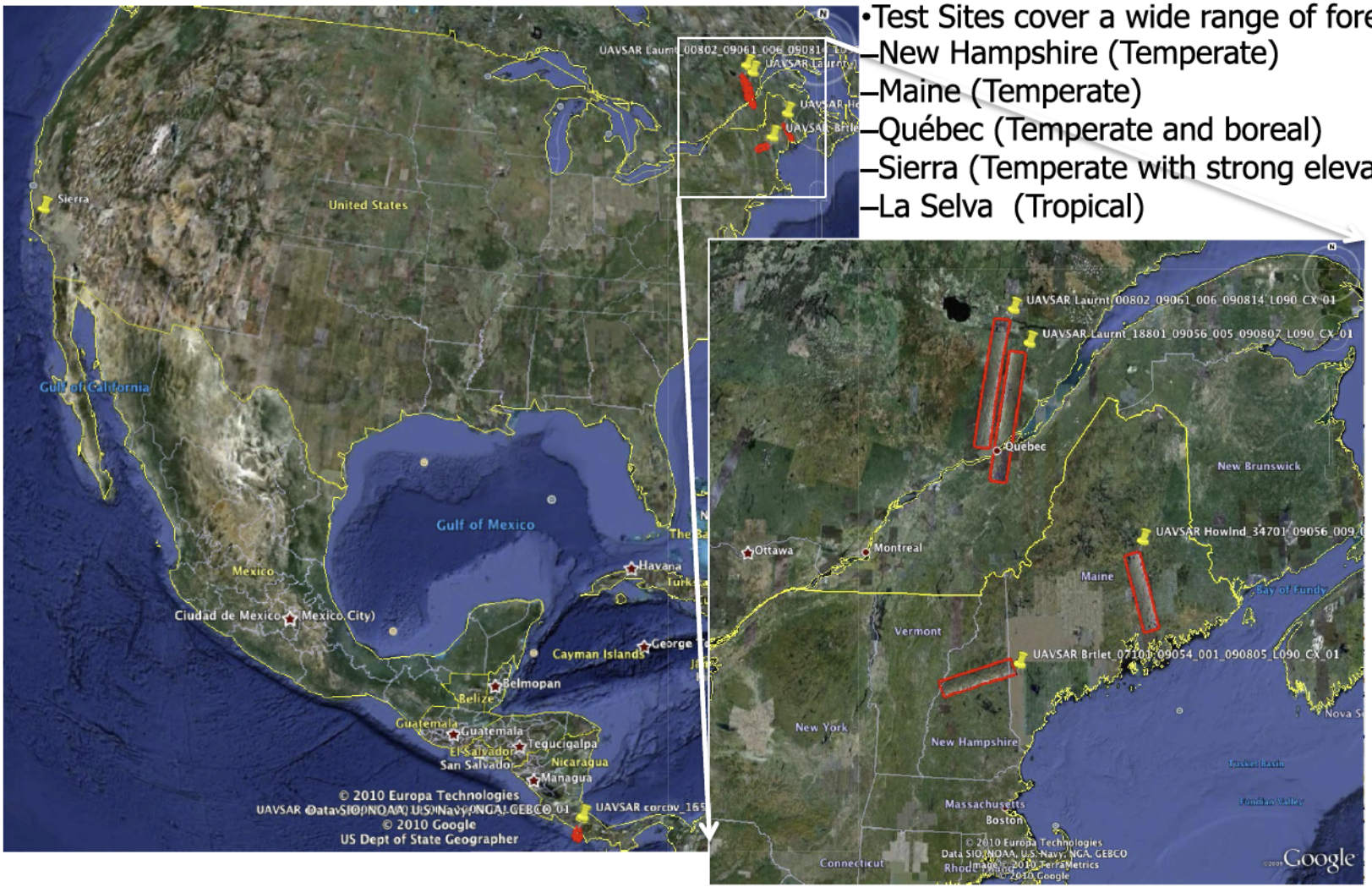
Google earth files: http:www-radar.jpl.nasa.gov/coastal

UAVSAR

- UAVSAR is an L-band fully polarimetric SAR employing an electronically scanned antenna that has been designed to support a wide range of science investigations.
  - The UAVSAR design incorporates:
  - A precision autopilot developed by NASA Dryden that allows the platform to fly repeat trajectories that are mostly within a 5 m tube.
  - Compensates for attitude angle changes during and between repeat tracks by electronically pointing the antenna based on attitude angle changes measured by the INU.

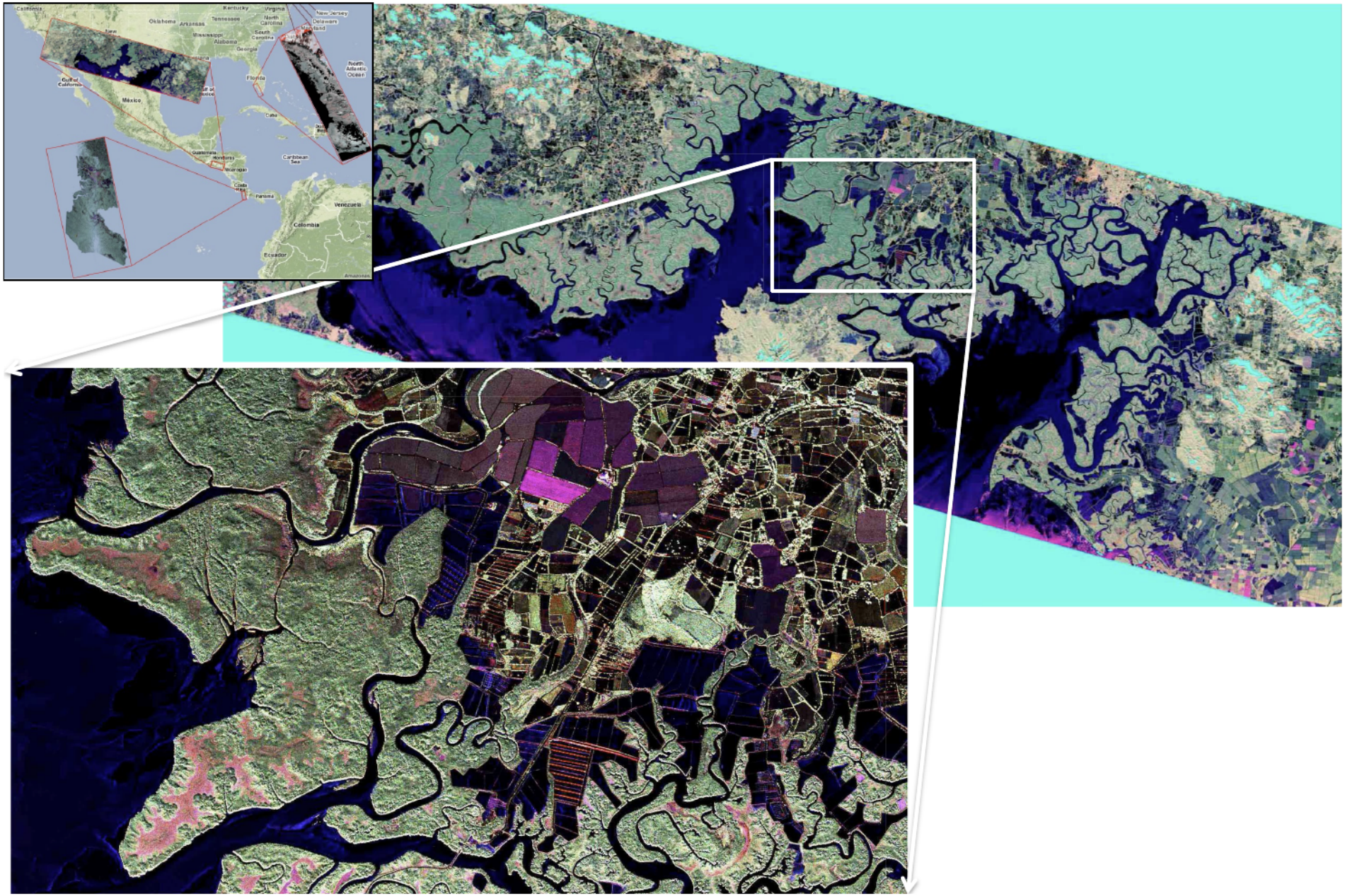
Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz
Bandwidth	80 MHz
Resolution	1.67 m Range, 0.8 m Azimuth
Polarization	Full Quad-Polarization
ADC Bits	2,4,6,8,10 & 12 bit selectable BFPQ, 180Mhz
Waveform	Nominal Chirp/Arbitrary Waveform
Antenna Aperture	0.5 m range/1.5 azimuth (electrical)
Azimuth Steering	Greater than ±20° (±45° goal)
Transmit Power	> 3.1 kW
Polarization Isolation	<-25 dB (<-30 dB goal)
Swath Width	> 23 km

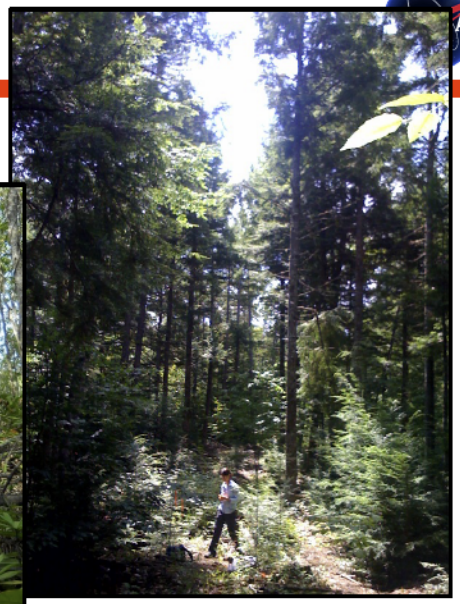
UAVSAR Campaign 2009-2010



- Test Sites cover a wide range of forest types and ter
  - New Hampshire (Temperate)
  - Maine (Temperate)
  - Québec (Temperate and boreal)
  - Sierra (Temperate with strong elevational gradient)
  - La Selva (Tropical)

New Project: Mangrove Vulnerability Assessment to Climate Change and Socio-Economic Pressure.



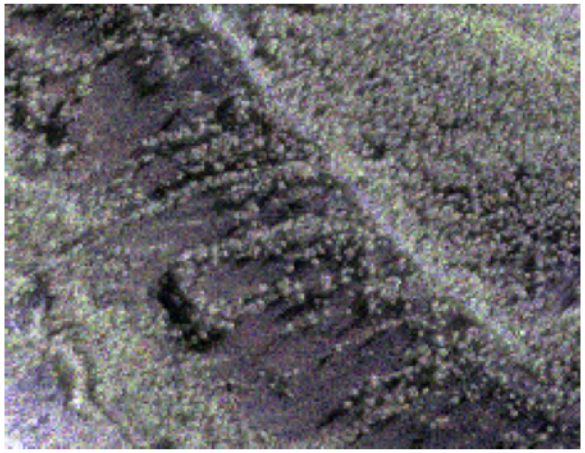


UNITED STATES OF AMERICA

Airborne and Field Data Collection

UAVSAR

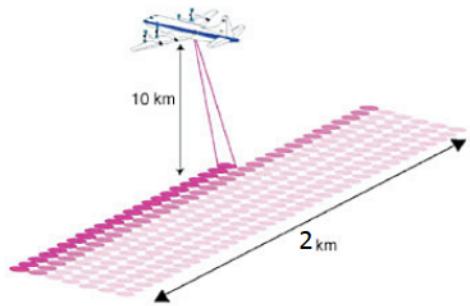
L-band polarimetric radar capable of repeat pass interferometry

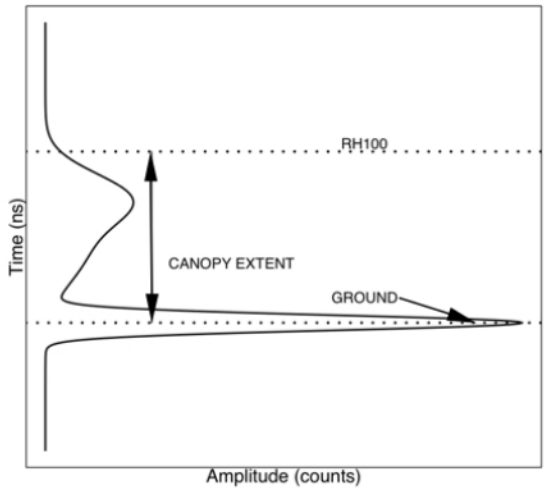


LVIS

Laser Vegetation Imaging System

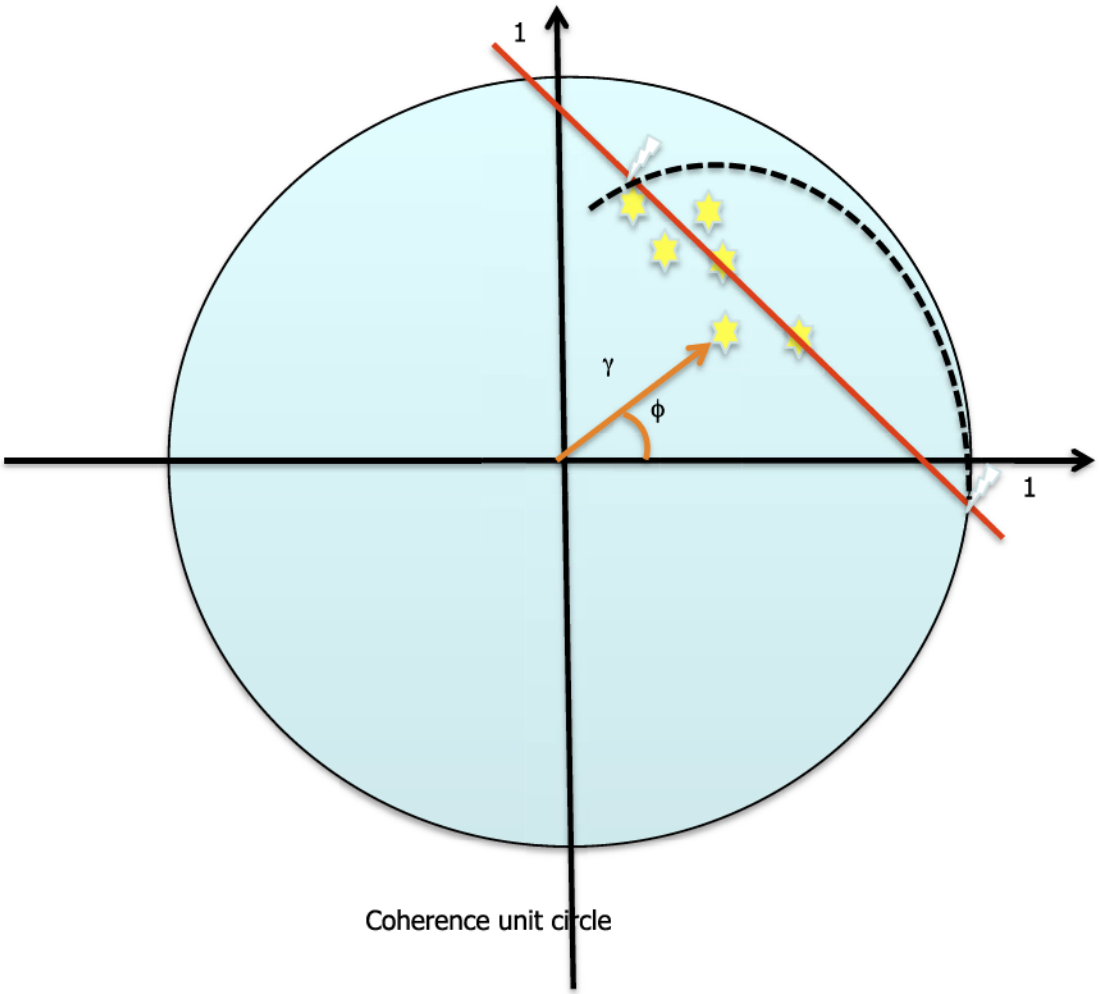
Full waveform lidar (25m footprint)

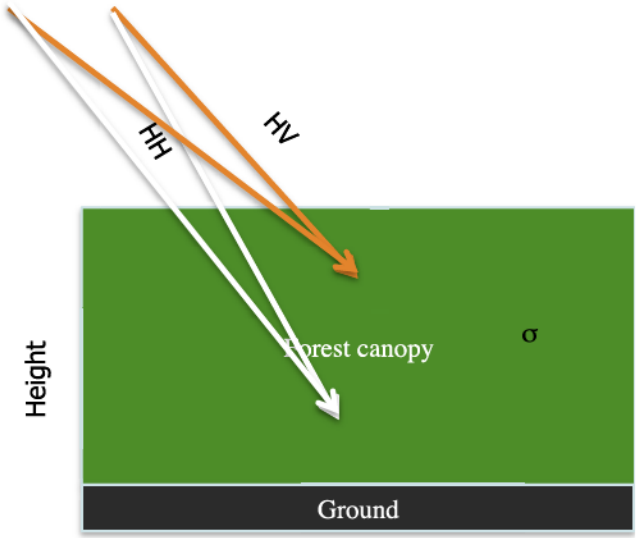




- Spatial resolution
  - UAVSAR: ~6m
  - LVIS ~25m
- Swaths
  - UAVSAR ~20km
  - LVIS 2km (based on max of 5º look for vegetation)
- Field data (88 forest plots)
  - Tree height;
  - Trunk diameter DBH
  - Tree species
  - Crown size
  - Terrain Slopes
  - Plot height and biomass

PolinSAR in pictures





PolinSAR results

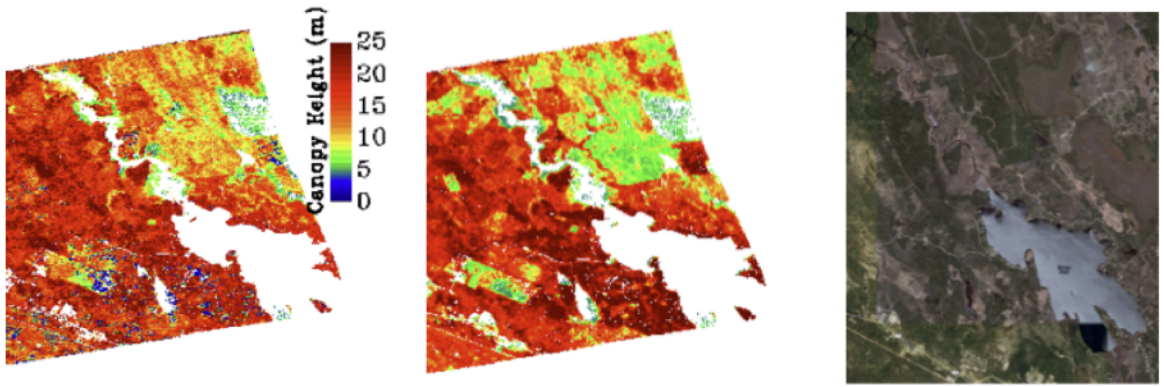
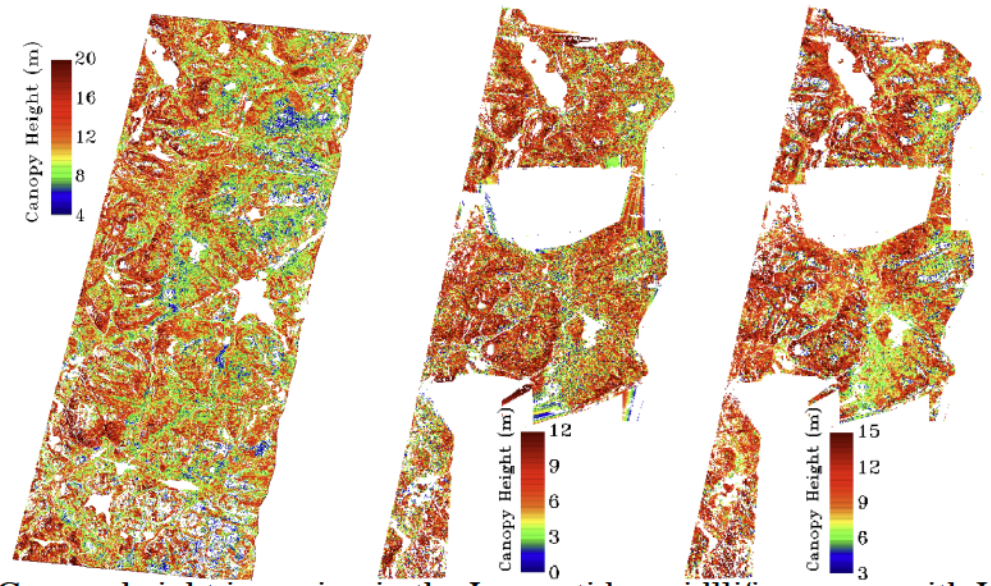


Figure 5: *PolinSAR inversion results using UAVSAR data (left) compared with LVIS*

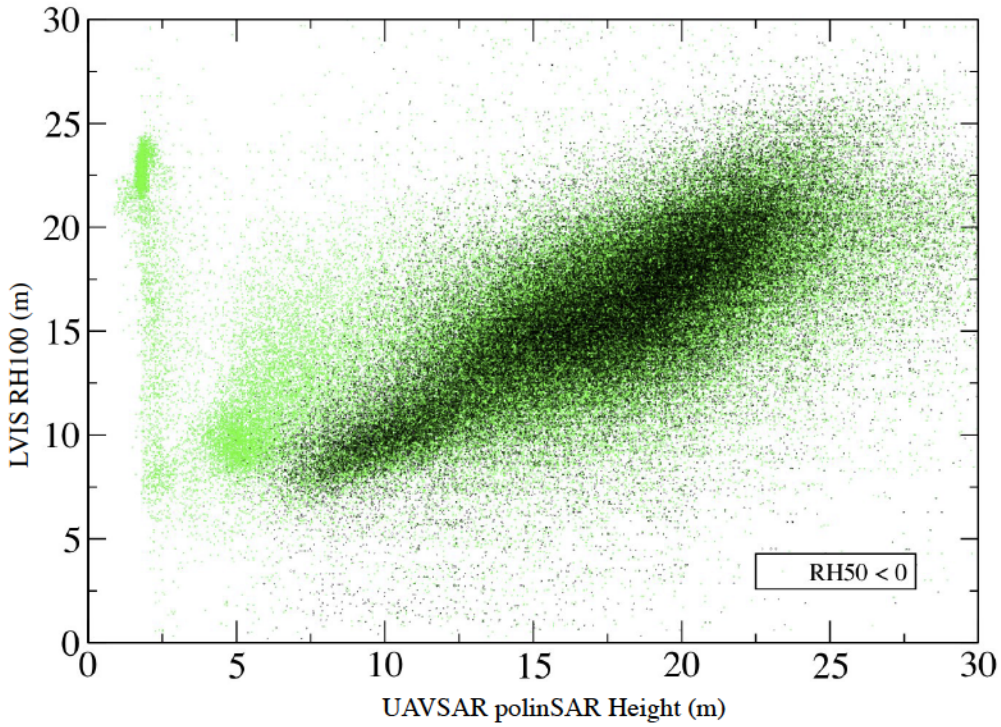
- Canopy height inversion in Chemo Pond, Maine, with UAVSAR (left), LVIS (center) and Google Earth (right).



- Canopy height inversion in the Laurentides widllife reserve with UAVSAR full swath (left), subimage (center) and small footprint lidar (right).

PolinSAR vs Lidar

- Validation of polinSAR with lidar data is limited.
  - Different measurements
    - Different spatial resolution
    - Different scattering properties.
    - Different geometries.

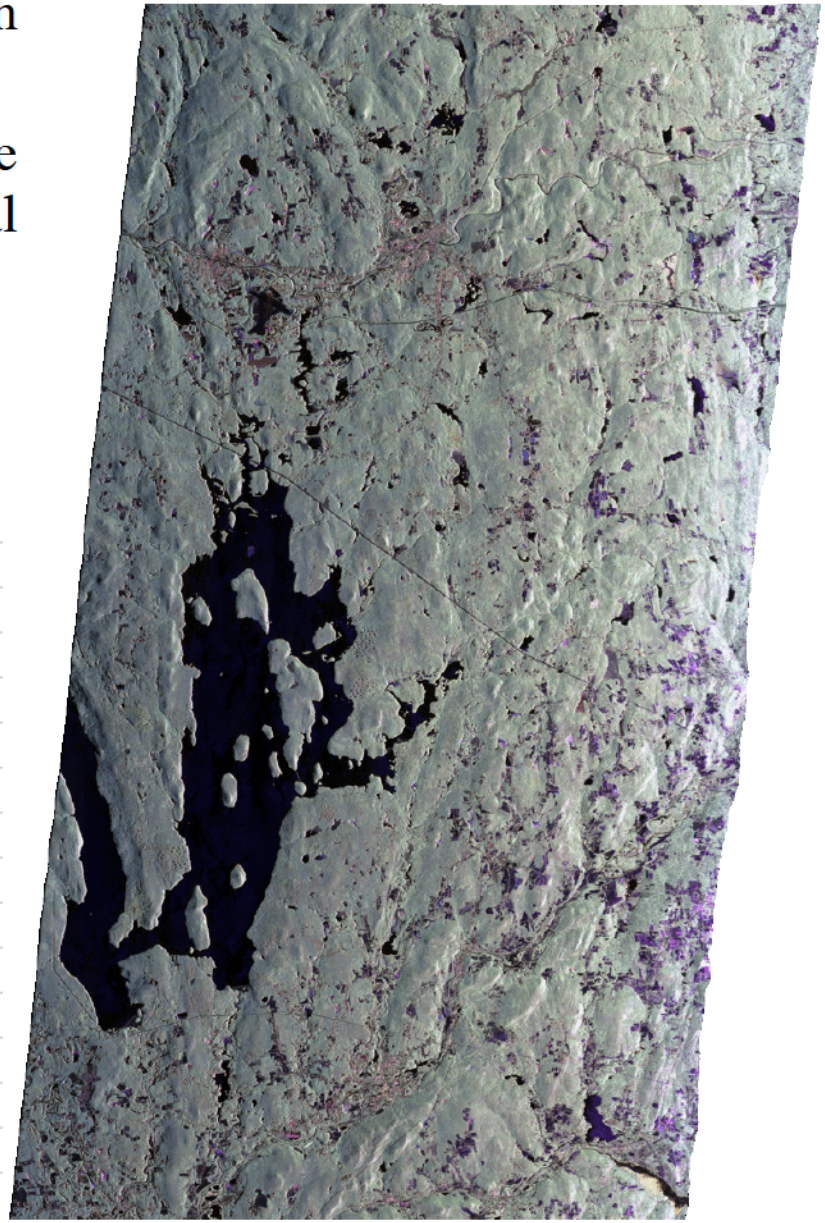


UAVSAR Radar Collections

- UAVSAR data was collected on dates from August 6-17, 2009.
- Lines were collected in both zero baseline and non-zero baselines to study temporal decorrelation and PolinSAR techniques.

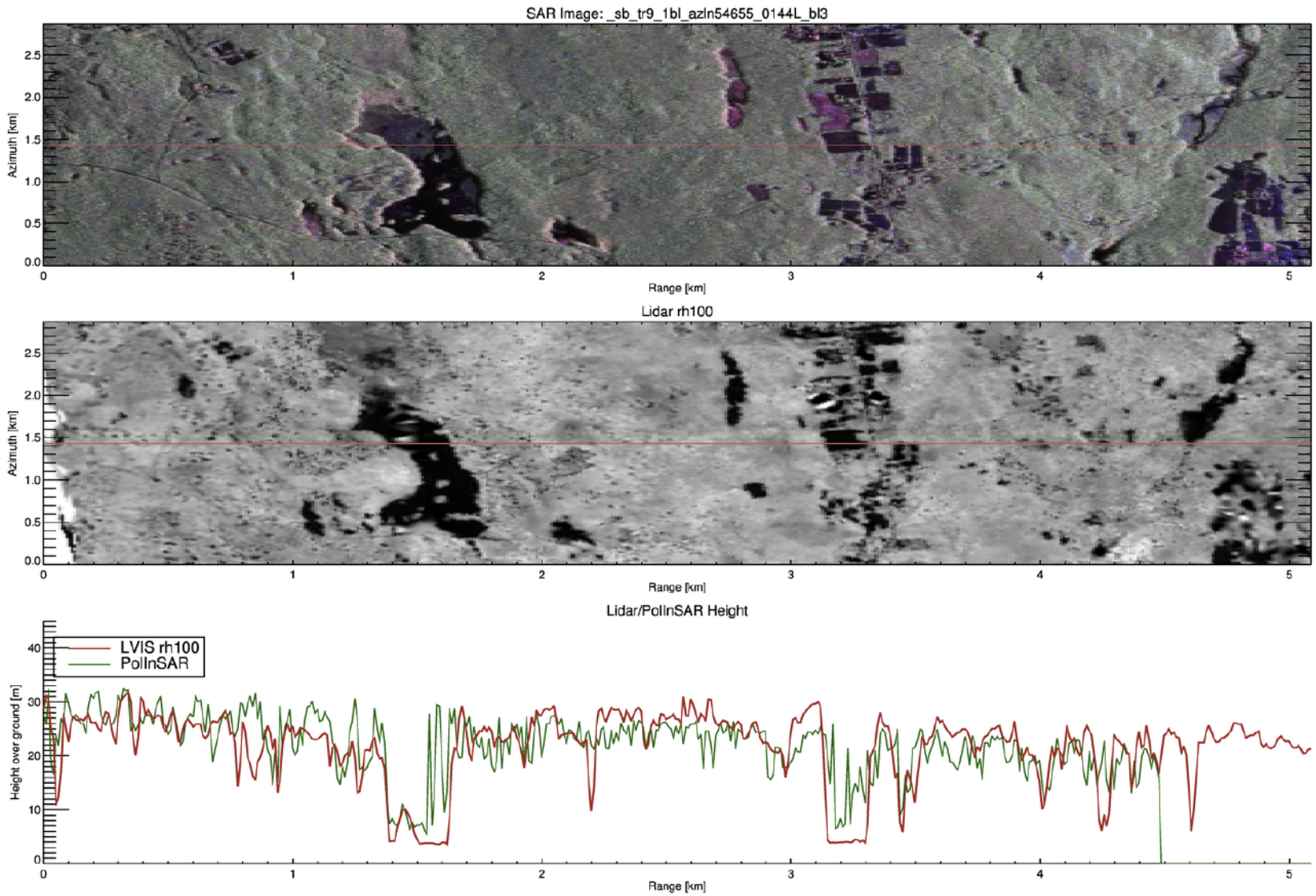
UAVSAR Image of Harvard Forest Region

Track Number	Date	Time of Day
1	August 6, 2009	13:59:57
2	August 6, 2009	14:31:27
3	August 6, 2009	15:01:56
4	August 6, 2009	15:32:54
5	August 8, 2009	15:13:26
6	August 8, 2009	15:43:51
7	August 8, 2009	16:14:49
8	August 13, 2009	19:15:09
9	August 13, 2009	19:48:39
10	August 16, 2009	13:51:11
11	August 17, 2009	14:57:43
12	August 17, 2009	13:58:03
13	August 17, 2009	13:28:53

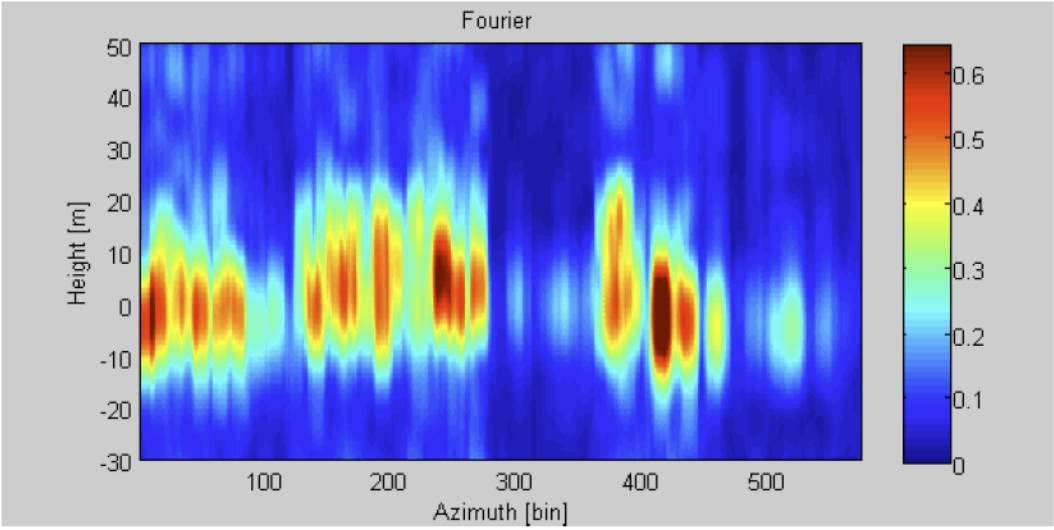


PolinSAR Tree Heights - 144 Looks

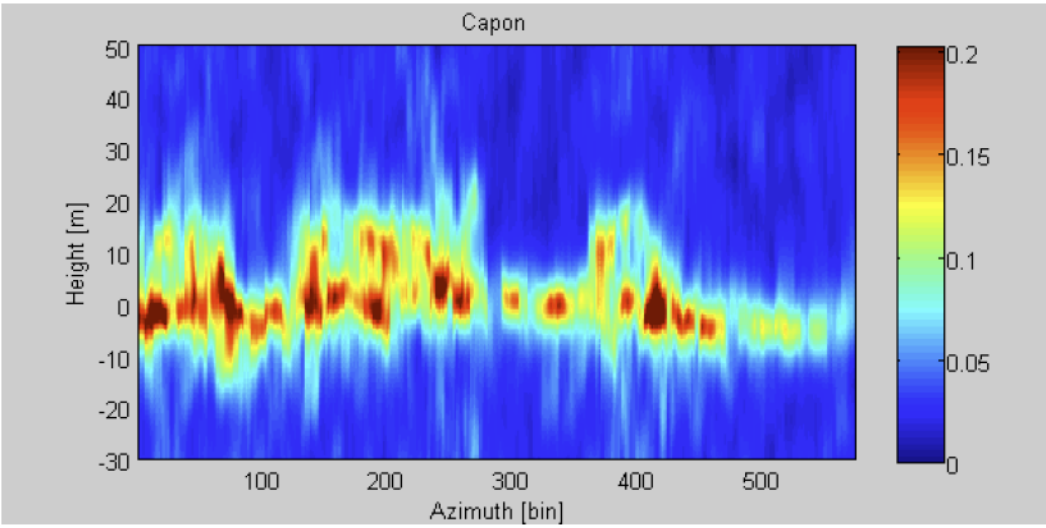
- Estimated tree heights from PolinSAR compared with lidar tree heights for 14 m^2 pixels or 144 looks.

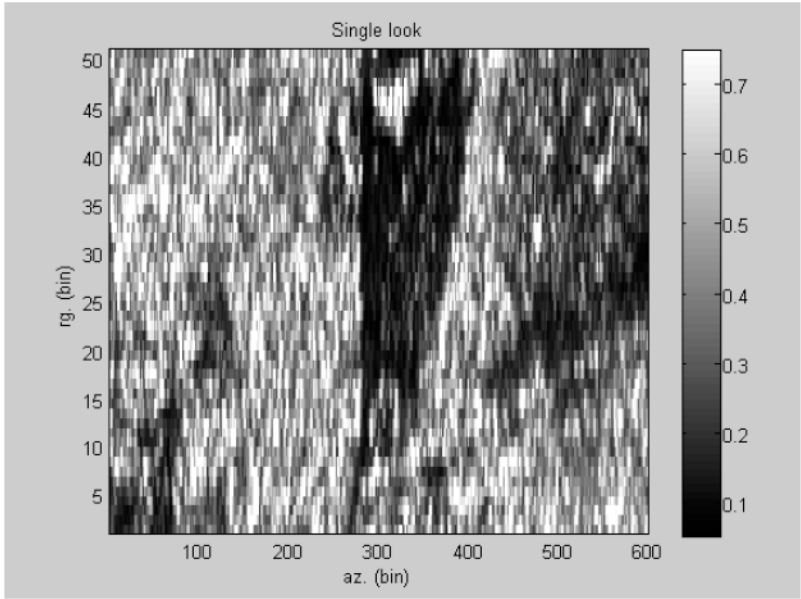


Fourier and Capon Tomograms– Site II



- Another Fourier and Capon tomogram for a cut at a larger range which leads to a coarser Rayleigh height resolution limit of 16 m (using 11 tracks).
- Forest structures are again clearly detected at the center of the tomogram, between two clearcut areas with fairly minor 3D imaging artifacts.





3D Land Mapping - Lidar and Radar Mapping of Land Surfaces

3D Land Mapping - Lidar and R...

lidarradar.jpl.nasa.gov

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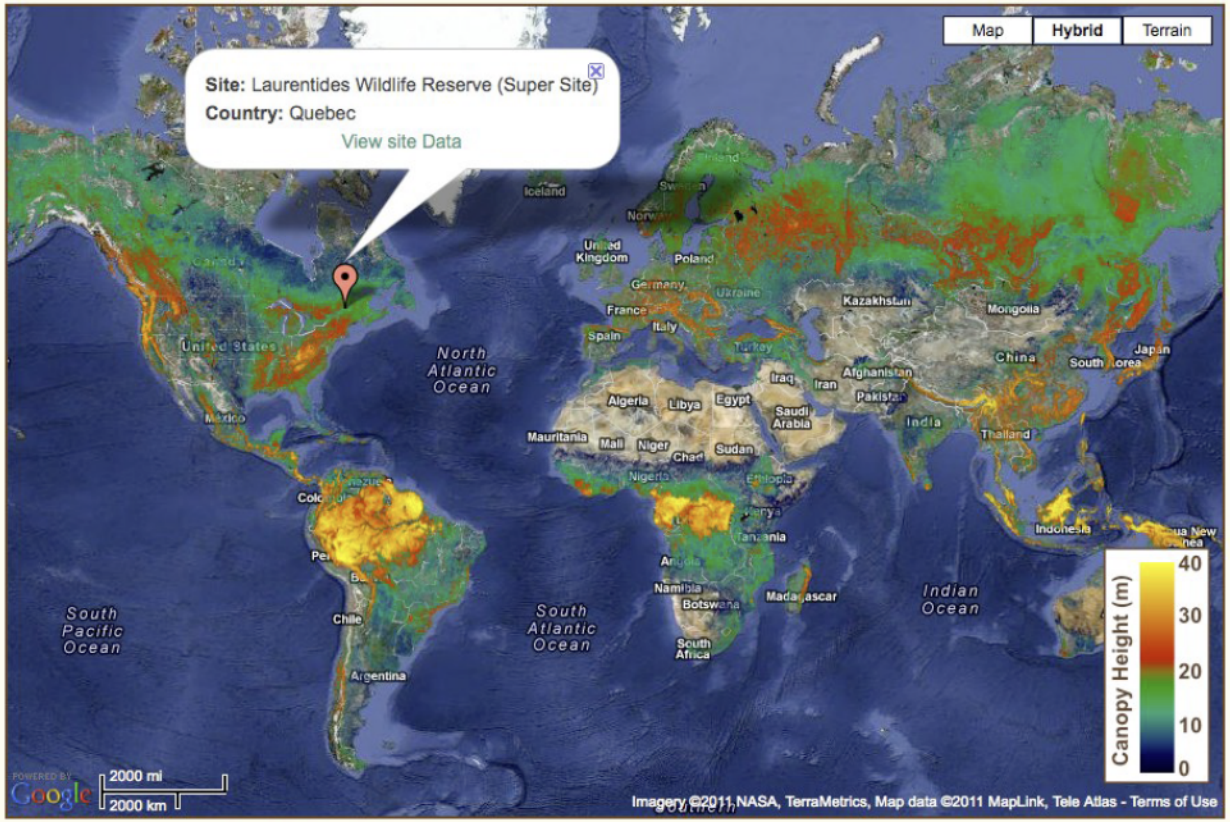
3D Land Mapping

Combining Lidar and Radar for Remote Sensing of Land Surfaces

Click on a marker to find out more information about your favorite site.



☑ Show low resolution (10km) 3D Global Vegetation Map derived from ICESat/GLAS and environmental modeling
Download the full resolution (1km) map here [TIF] and map legend here. An error map can be downloaded here.

Project Description

This website presents the research projects of Dr. Marc Simard, Senior Scientist at the Jet Propulsion Laboratory. **The overall objective is to combine radar and lidar remote sensing to characterize the forested landscapes in 3D.** The science products generated by Simard and

3D Land Mapping – Laurentides Wildlife Reserve, Quebec

3D Land Mapping – Laurentides...

lidarradar.jpl.nasa.gov/sites/laurentides.html

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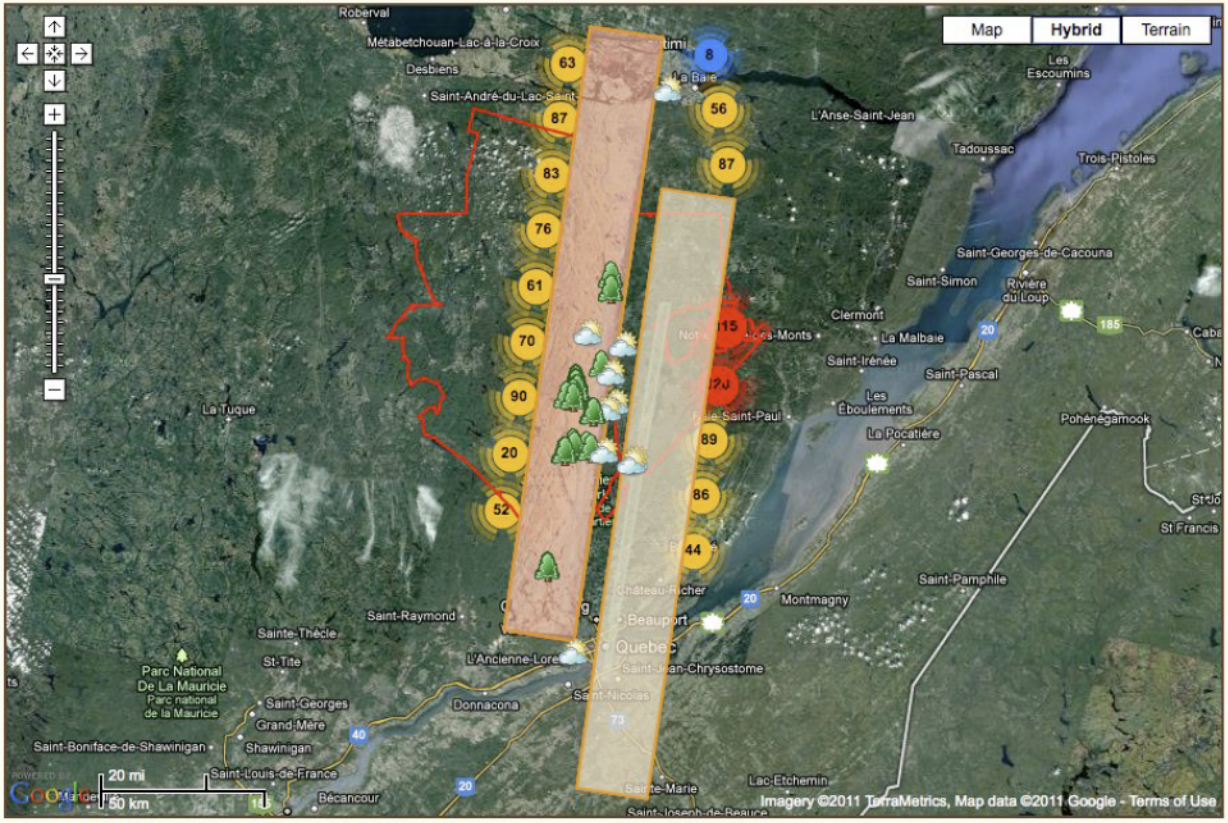
Super Site: Laurentides Wildlife Reserve, Quebec

Click a checkbox to show a specific dataset in the map. Then click the objects (markers, swaths, etc) in the map for more information.

☑ Super Site [KML] ☑ UAVSAR ☑ LVIS ☑ ICESat [TXT] ☐ SRTM [KMZ] ☑ Field Data [CSV] ☑ Weather Data [KML]



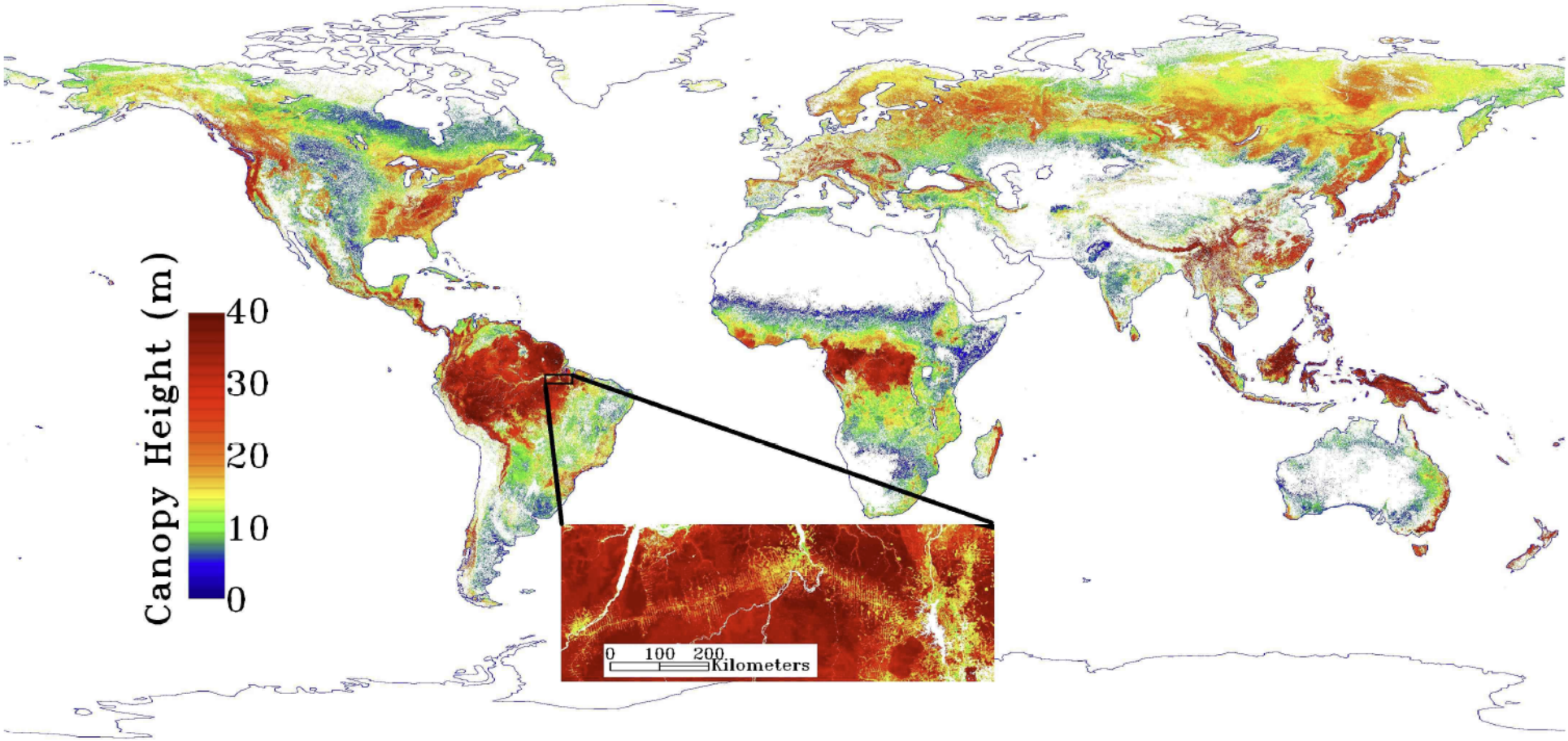
Lat: Lng:

UAVSAR Swath Details: Laurnt_00802

Radiometrically Calibrated Backscatter (View a high-resolution map here)

Low-resolution: [KML], GeoTIFF files by polarization: [HH] [HV] [VV]

Global Map of Forest Canopy Height (1km resolution)



Simard et al. (Journal of Geophysical Research, 2011)