Module 2.8 Overview and status of evolving technologies

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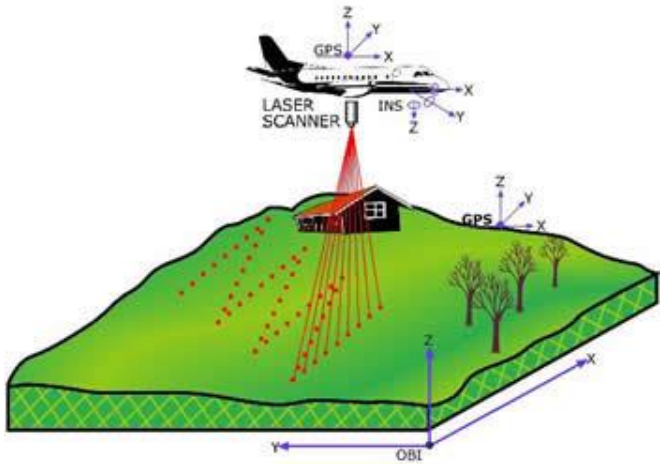
After the course the participants should be able to:

- Mention and characterize existing evolving technologies in remote sensing for measuring and monitoring purposes for REDD+; their status and near-term developments
- Describe the measurement techniques using LIDAR and RADAR data



US Forest Service

V1, May 2015

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GOFC-GOLD Global Observation of Forest and Land Cover Dynamics

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Outline of lecture

1. Role of LIDAR observations for forest characterization and experiences with LIDAR for monitoring purposes
2. The use of RADAR for forest monitoring

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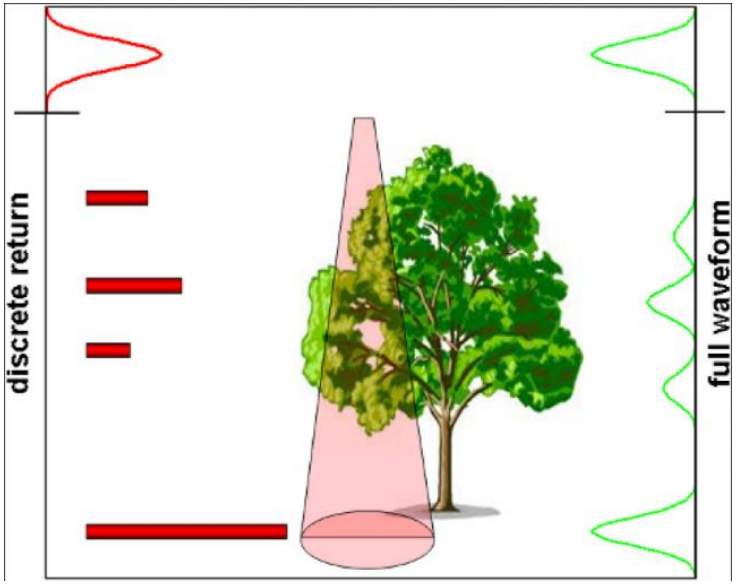
1. **Role of LIDAR observations for forest characterization and experiences with LIDAR for monitoring purposes**
2. The use of RADAR for forest monitoring

LIDAR: Background and characteristics

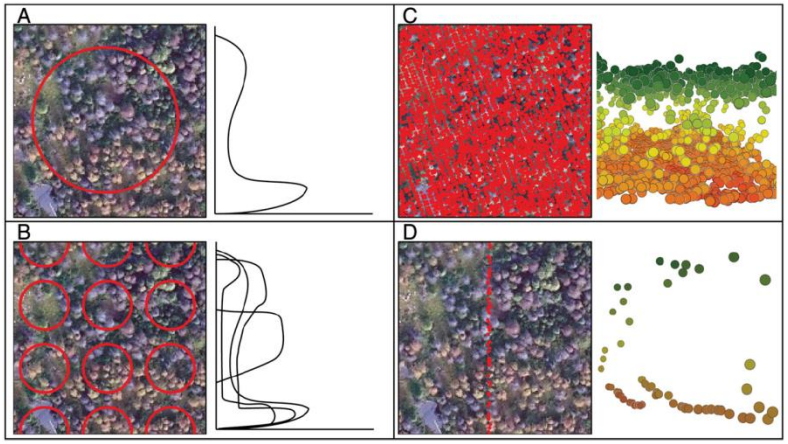
- LIght Detection And Ranging (LIDAR) technology uses **active sensors**
- Information obtained from lasers to estimate the **three-dimensional distribution** of vegetation canopies as well as subcanopy topography
- LIDAR systems classified as either **full waveform** or **discrete return** sampling systems, further divided into **profiling** and **scanning systems**
- LIDAR sensors can estimate tree/stand height, volume, biomass, and stand crown closure



Ussyshkin 2011.

Experiences for monitoring purposes (1/3)

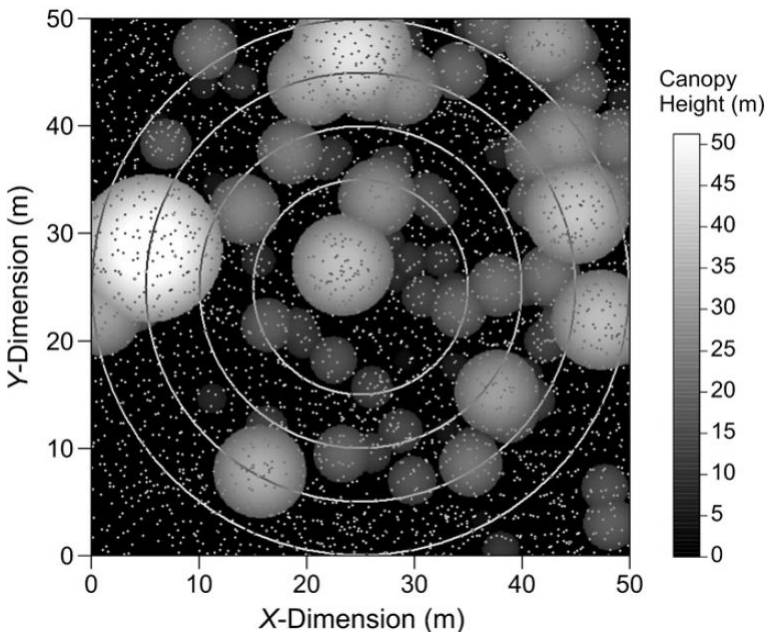
- **Height estimates** obtained from airborne remotely sensed LIDAR data have similar or better accuracy than field-based estimates
- LIDAR measurement errors can be < 1.0 m for individual tree heights of a given species
- **LIDAR** measurements have no saturation effect
- **Ground measurements required** to estimate **relationships** between three-dimensional properties of **LIDAR point cloud** such as canopy height and canopy density and target **biophysical properties** of interest such as biomass, using parametric or nonparametric statistical techniques



A: spaceborne waveform,
B: airborne waveform
C: discrete return scanning LIDAR
D: discrete return profiling LIDAR
(Wulder et al. 2012)

Experiences for monitoring purposes (2/3)

- Wall-to-wall mode or sampling mode can be used to monitor large areas
- Consider sources of error in ground allometric models
- More research needed to better assess/consider model errors associated with three-stage LIDAR sampling methods
- Co-registrations errors between ground plots and LIDAR data: larger plots (radius >=25m) provide improved biomass accuracy



Frazer et al. 2011.

Experiences for monitoring purposes (3/3)

- **Costs**: vary widely, depend on area to monitor (economies of scale possible). In Europe: $0.5-1.0 per hectare, greater in South America using local companies
- Recent bids for complete, wall-to-wall LIDAR coverage for a REDD+ demonstration in Tanzania from European data providers were on the order of $0.5-1.0 per hectare
- Airborne LIDAR technology may be **more cost-effective** than other remote sensing technologies, even when data are acquired free of charge, because **fewer field observations** may be needed to satisfy specified precision level

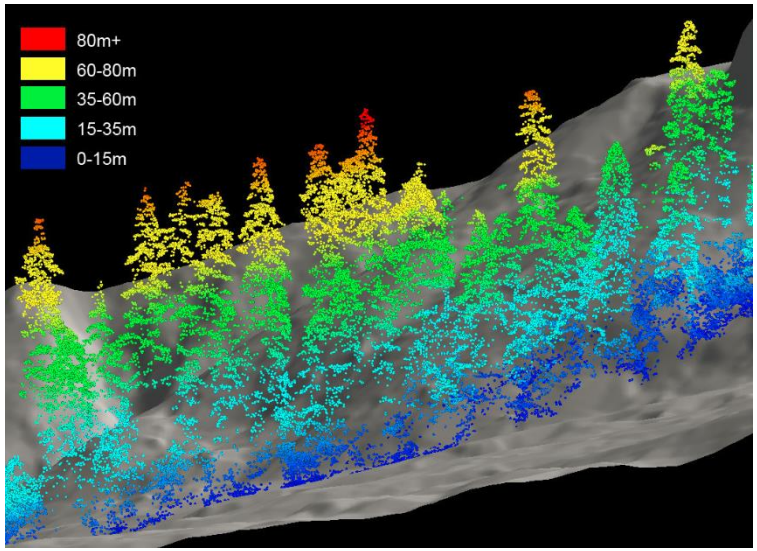


Photo credit: Spies and Olsen, Oregon State U.

Data availability and required national capacities (1/2)

- Spaceborne LIDAR data available globally based upon GLAS data, freely available through the National Snow and Ice Data Center, NSIDC (operational period: 2003–2009)
- Airborne LIDAR data can be acquired for any part of the world, with coverage on-demand via commercial agencies
- Airborne data can be collected theoretically anywhere, but costs are typically greater for more unusual locations and where implementation of the survey is more difficult
- Airborne data can be collected by a variety of instruments, over a range of settings, resulting in data with varying qualities
- Low-flying aircraft requires agreements / participation of national agencies

Data availability and required national capacities (2/2)

Summary of LiDAR survey flight and sensor parameters.

Attribute	Value
Platform	PA31 Piper Navajo
Flying height (m)	450 to 1,900 m
Sensor	ALTM 3100C
Maximum number of returns	4
Laser wavelength (nm)	1,064
Pulse repetition frequency (kHz)	50 or 70
Maximum scan angle (degrees)	±20
Beam divergence angle (mrad)	0.3
Footprint diameter (m)	Varying according to altitude of flight
Average swath width (m)	630
Average nominal ground return density (returns/m^2)	2.8

Mora et al. 2013.

Status, expected near-term developments, and long-term sustainability

- Currently no operational space laser
- NASA working toward development of new spaceborne LIDAR mission to be flown on ICESat II with utility for estimation of vegetation structure, height, and biomass currently unknown
- Launch of ICESat II scheduled for 2017 (http://icesat.gsfc.nasa.gov/icesat2/mission_overview.php)
- LIDAR Surface Topography mission (LIST) to collect global LIDAR data over a five-year mission also planned for launch in the 2020s by NASA

Applicability of LIDAR for forest monitoring (1/2)

- LIDAR is an emerging technology in terms of large-area monitoring, especially for REDD+
- However, well established as a data source for contributing to satisfaction of forest management and science objectives
- Capacity for LIDAR to characterize biomass and biomass change over time positions the technology well to meet REDD+ information needs
- "Costs to a program need to be vetted against the information that is acquired, how this information meets the specified needs, and the degree to which the reduction in uncertainty from LIDAR-based estimates offsets initial costs" (Wulder et al. 2012)

Applicability of LIDAR for forest monitoring (2/2)

Technical capabilities of remote sensing sensors for the generation of (national) REDD+ information products

Forest information product	Sensor type						
	Optical/thermal			Radar/SAR		LiDAR	
	Coarse	Medium	Fine	Medium	Fine	Satellite (Large footprint[a])	Airborne (Small footprint[a])
Forest area change monitoring							
Near real-time deforestation detection							
Land use change patterns and tracking of human activities							
Forest degradation monitoring							
Monitoring of wildfires and burnt areas							
Biomass mapping							
Sub-national hotspot monitoring							
Forest type mapping							

[a]Footprint is the ground instantaneous field-of-view, which is a measure of the ground area viewed by a single detector element in a given instant in time.

- Very suitable
- Suitable
- Contributing
- Limited to no technical capabilities

De Sy et al. 2012.

In summary

- LIDAR technology uses active sensors
- LIDAR sensors can estimate tree/stand height, volume, biomass, and stand crown closure
- LIDAR measurements have high accuracy, comparable to field measurements
- Relationships are established between three-dimensional properties of LIDAR point cloud (canopy height and canopy density) and biophysical properties (biomass), using allometric equations
- LIDAR is an emerging technology in terms of large-area forest monitoring, especially for REDD+

Outline of lecture

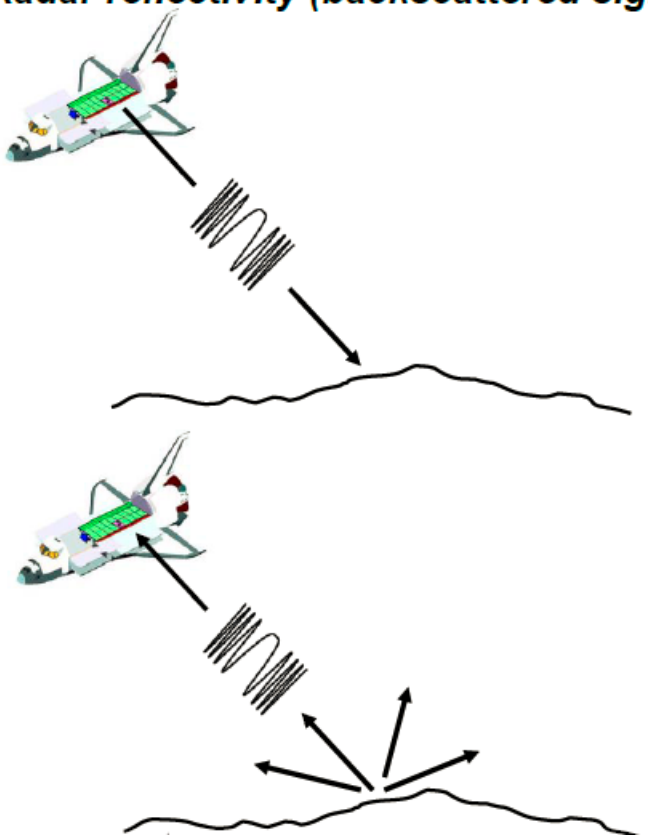
1. Role of LIDAR observations for forest characterization and experiences with LIDAR for monitoring purposes
2. **The use of RADAR for forest monitoring**

Synthetic Aperture Radar (SAR) technology

- SAR sensors used since the 1960s to produce images of earth-surface based on the principals of **radar** (radio detection and ranging) **reflectivity**
- SAR based on relative motion between sensor's antenna and target: implemented using usually a **moving platform** (aircraft, space shuttle, satellite)
- Radar is an **active system**, meaning it serves as the source of its own electromagnetic energy

Radar backscattering mechanisms (1/3)

- ***Radar reflectivity (backscattered signal) of the target as a function of position***

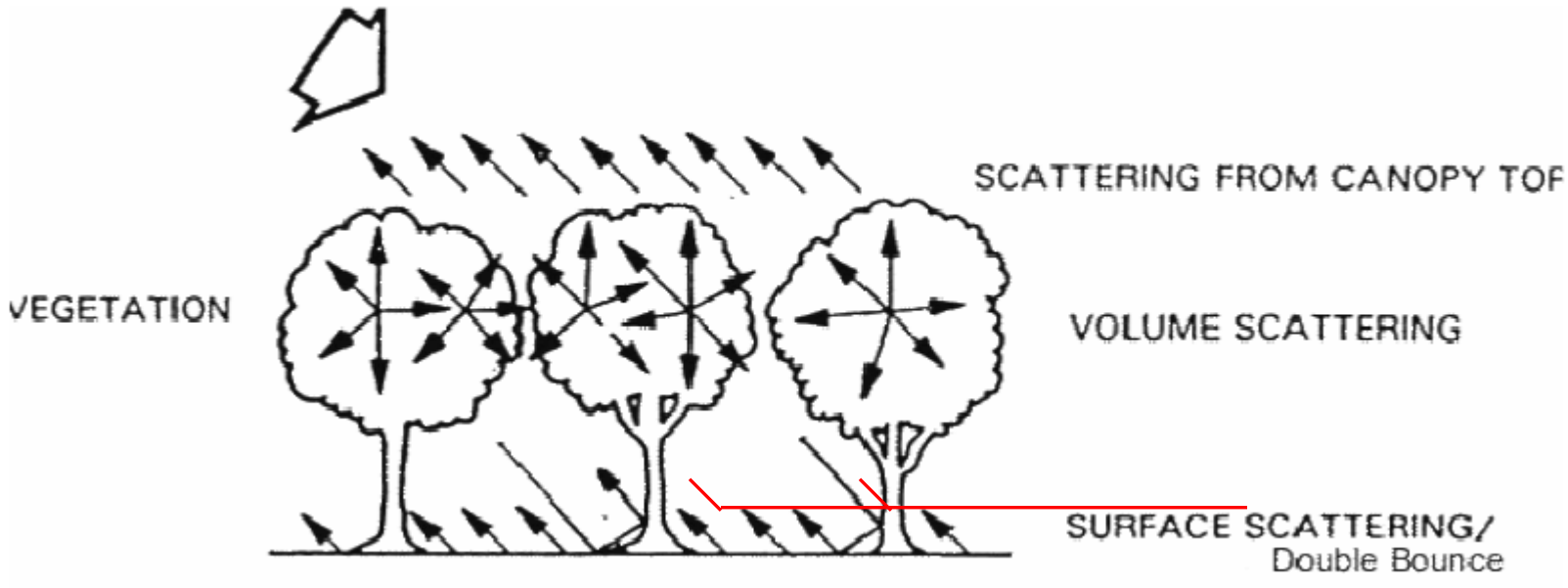


- Radar transmits a pulse (travelling velocity is equal to velocity of light)

- Some of the energy in the radar pulse is reflected back toward the radar
- This is what the radar measures: It is known as radar backscatter σ_0

Source: Lopez-Dekker 2011.

Radar backscattering mechanisms (2/3)



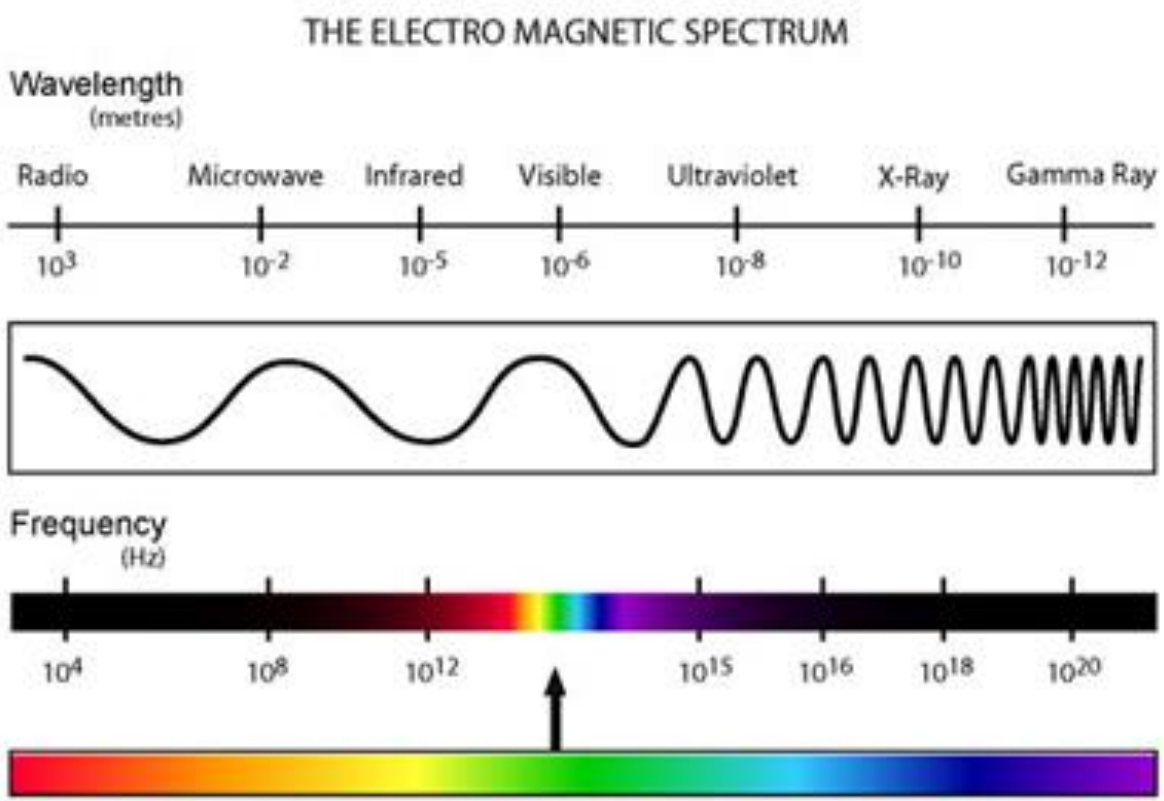
Source: Thiel 2011.

Location of radar in the electromagnetic spectrum (1/2)

- While optical sensors operate primarily in the visible and infrared (ca. 0.4-15.0 µm) portions of electromagnetic spectrum, radar sensors operate in **microwave region** (ca. 3-70 cm)
- Electromagnetic waves in visible and infrared range are scattered by **atmospheric particulates** (e.g., haze, smoke, and clouds); **microwave signals generally penetrate through them**

  => added value for imaging tropical forests covered by **clouds**

Location of radar in the electromagnetic spectrum (2/2)



Source: http://canadiansubsurface.com/ir.html

Preprocessing of radar signal

- Radar signal requires preprocessing to deal with:
  - Geometric distortions such as foreshortening and layover
  - Topographic effects resulting in different illumination conditions in the scene
  - Speckle noise

- Commercial and noncommercial software are available

Radar Processing

- ALOS Palsar FBD data
- From Alaska Space Facility (vast archive for South America, Africa, SE Asia)
- Can be used from NGOs etc.
- End User License Agreement, on every image should be stated:
- Includes Material (c) JAXA, METI [year]

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Radar Processing

- SAR data
  - Main advantages:
    - No clouds
    - Day and nighttime (i.e. active sensor)
    - Sensitive to biomass (especially L-Band like ALOS Palsar)
- Example Zambia
  - ~ 400 scenes (750000km2)
  - Processing duration: ~ 5 days
  - Output data size of final stack: 77GB

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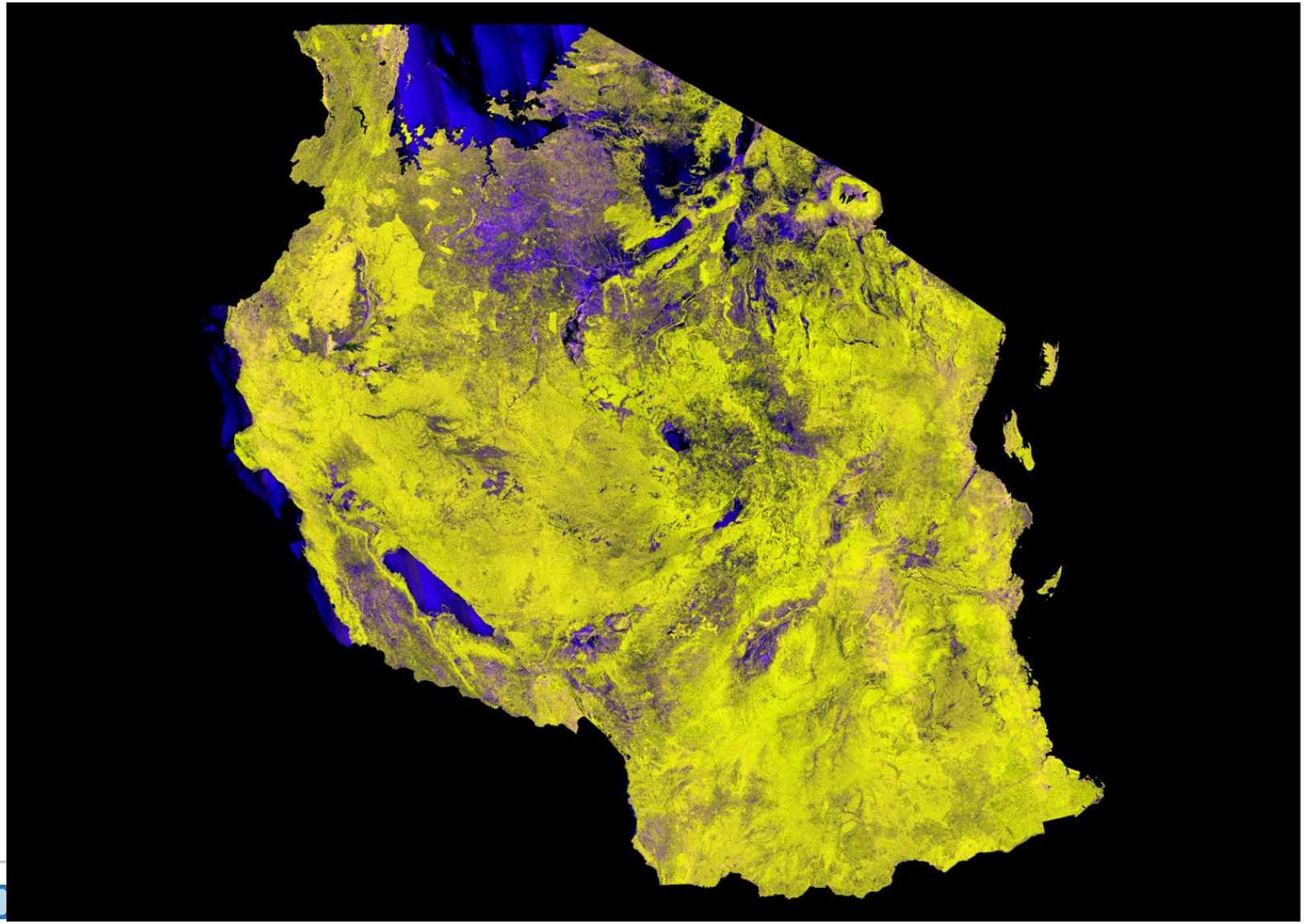
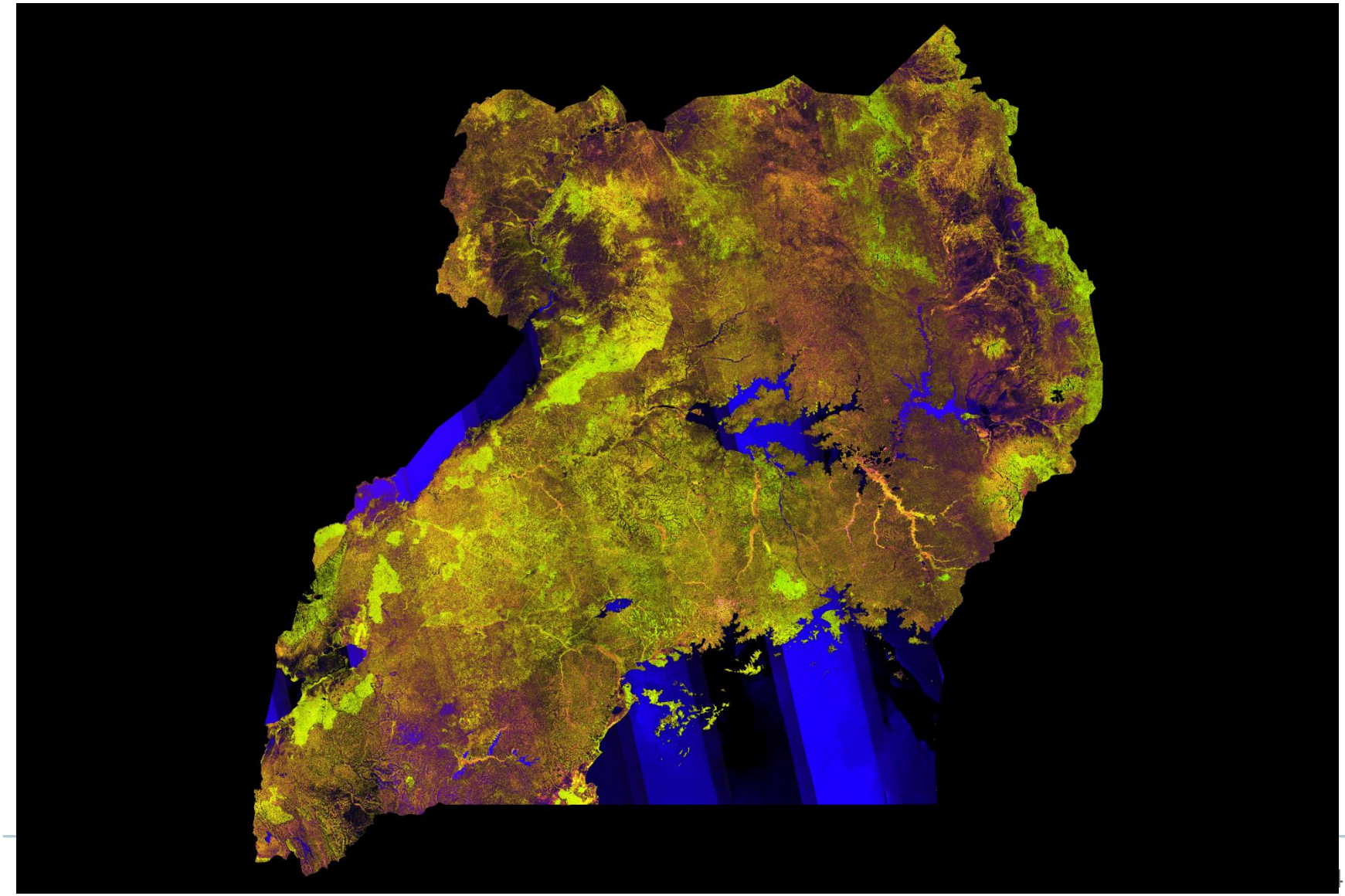
Tanzania 2007



Includes Material © JAXA, METI 2010

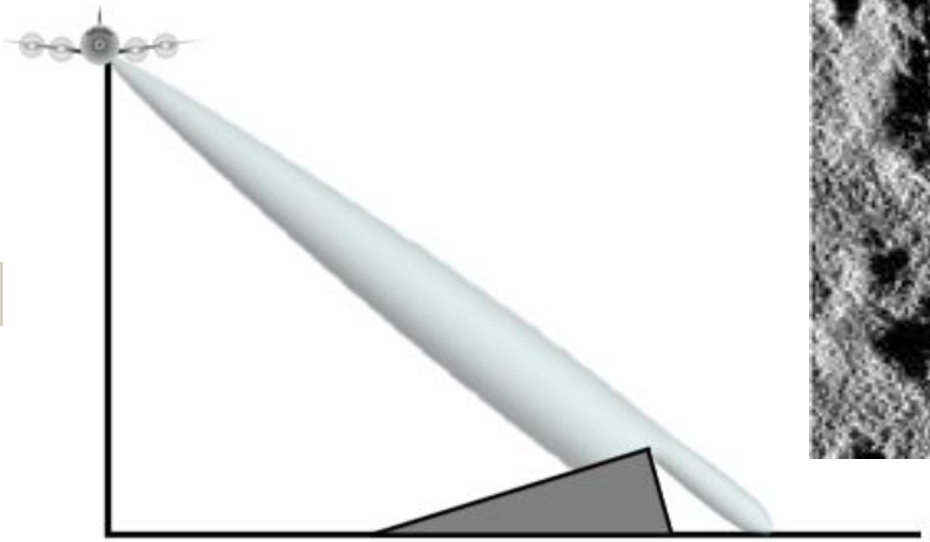
REDD+ training materials by GFOI-GOFC-GOLD, Wageningen University, World Bank FCPF

Uganda 2007



Topographic effects

Shadowing



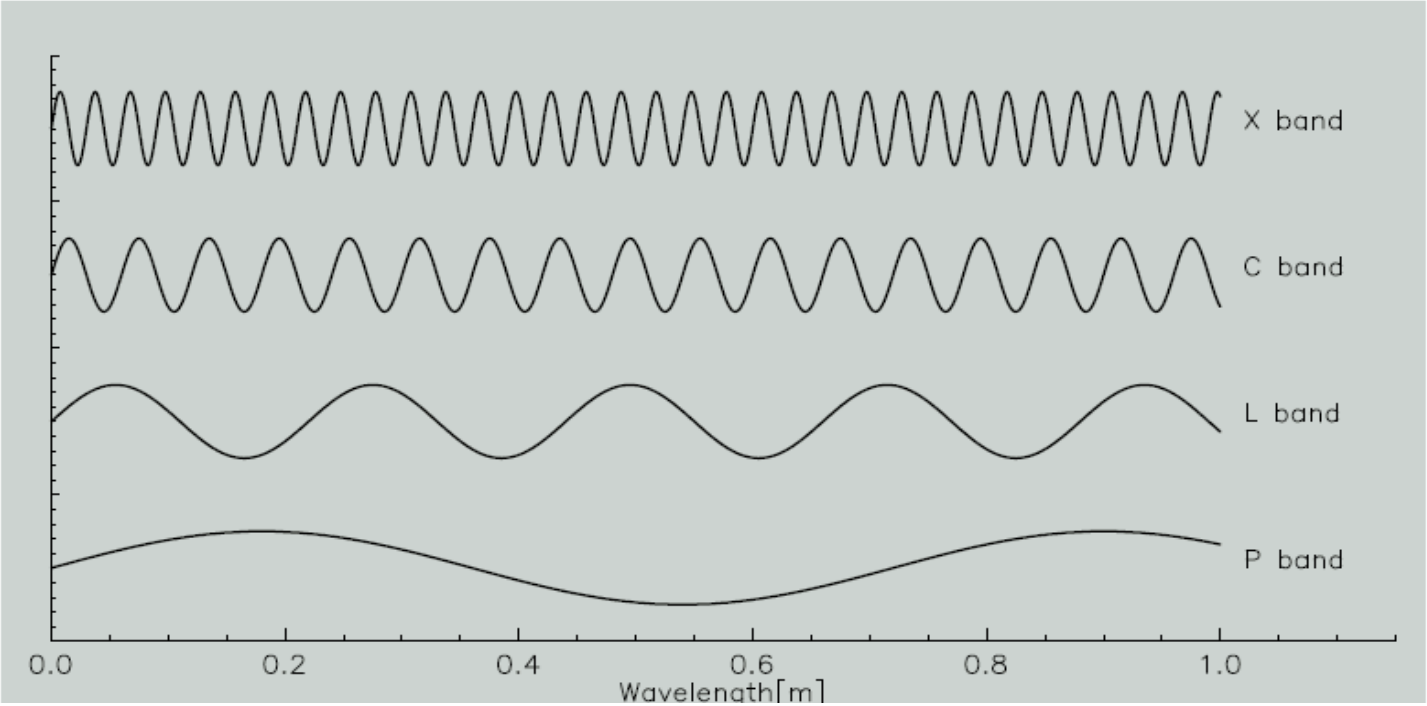
Source: Radiotutorial n.d., http://www.radartutorial.eu/20.airborne/ab07.en.html.

Radar band characteristics (1/4)

- Active: radars illuminate the target so that they can operate day and night
- Microwave frequencies:
  - Electromagnetic waves penetrate to some extent through media
  - At most frequencies clouds are transparent
- Complex interaction with medium or target: a radar image is not a photo
- Spatial resolution fundamentally constrained:
  - Do not expect 1cm resolution SAR images at C-band

Band	Typical frequency (GHz)	Wave-length (cm)
P	0,350	85
L	1.3-1.4	23-21
C	5.3-5.4	5.6-5.5
X	9.65	3.1
Ku	12-18	2.5-1.6
Ka	35	0.8

Radar band characteristics (2/4)

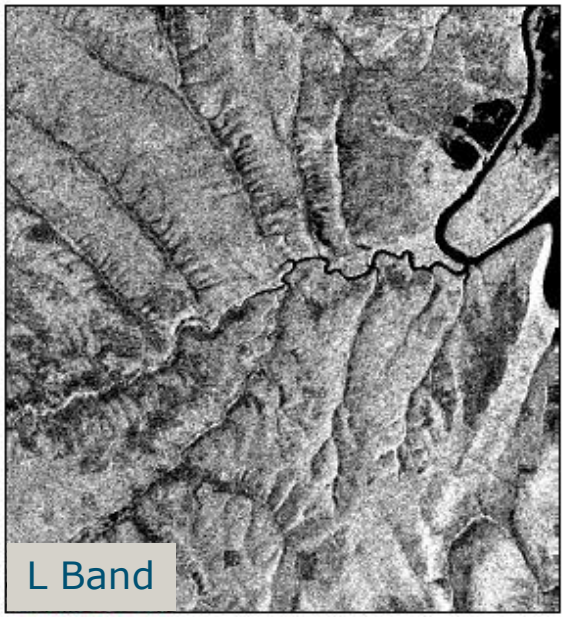


Source: Lopez-Dekker 2011.

Radar band characteristics (4/4)

Forest at different frequencies

- Small dynamic range
- Variable response to water
- Variable response to open areas
- Can be used as indicator of environmental effects effecting the coherence



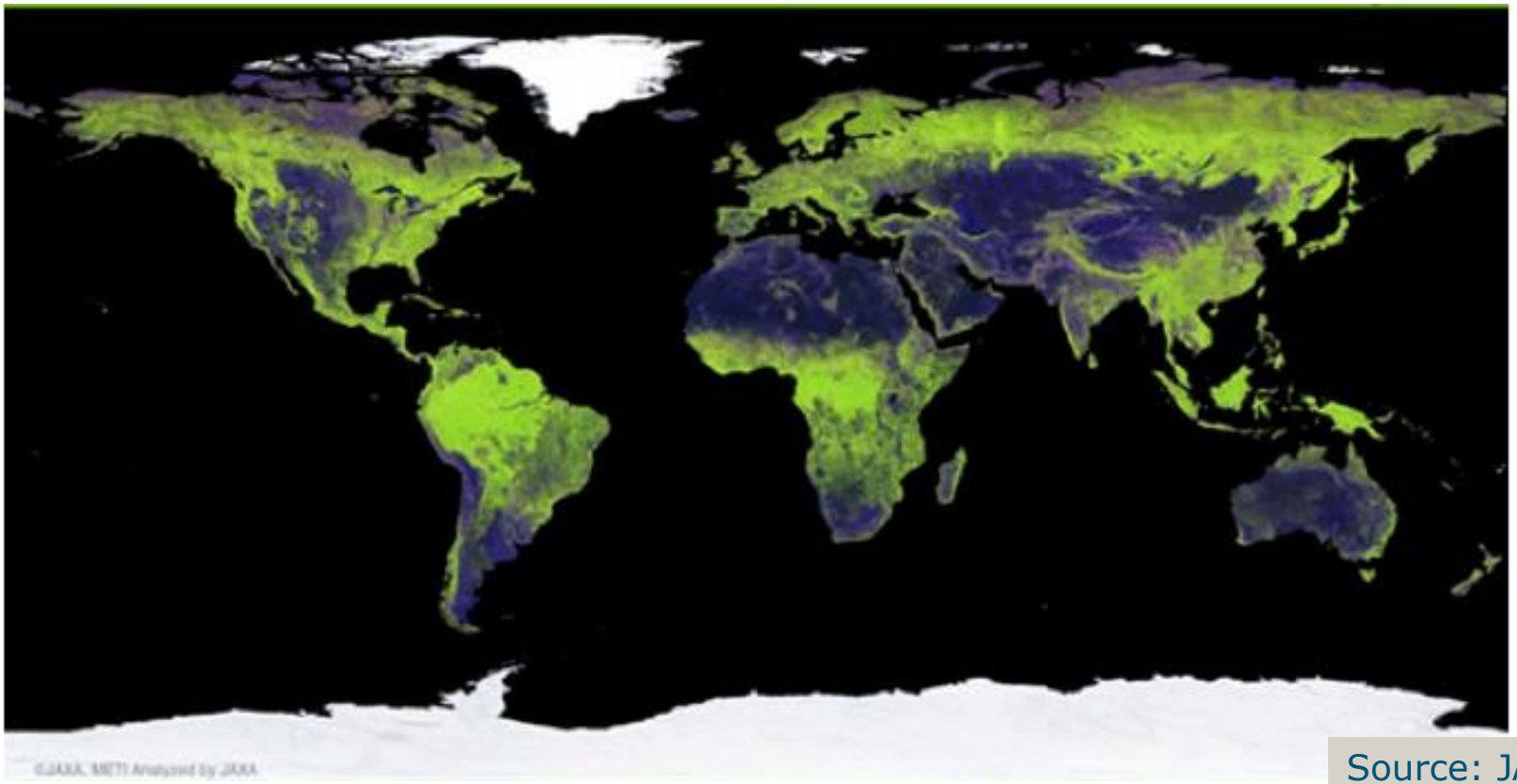
- Medium dynamic range
- Stable response to water
- Possible to identify agricultural fields
- Higher frame to frame variations

Source: Thiel 2011.

Radar for forest monitoring

Global ALOS PALSAR color composite mosaic

(Red:HH, Green:HV, Blue:HH/HV), 25 m pixel spacing, 70,000 scenes, acquired between June-October 2009



Source: JAXA 2009

Radar for forest monitoring

SAR (Shuttle Radar Topography Mission **SRTM data**) demonstrated capacity for **retrieving forest height** across larger areas:

- JERS-1 SAR mission provided **first consistent pan-tropical and pan-boreal observations**; long wavelength L-band SAR data proved useful for forest/nonforest classification and identification of secondary growth
- L-band data also facilitated temporal mapping of standing water below closed-canopy forests with time-series => floodplain versus swamp forests differentiation

Past, current, and future SAR missions (1/2)

Satellites/ sensors	Period of operation	Band	Wave-length (cm)	Polarisation	Spatial resolution (m)	Orbital repeat (days)
ERS-1	1991–2000	C	5.6	Single (VV)	26	3–176
JERS-1	1992–1998	L	23.5	Single (HH)	18	44
ERS-2	1995–2011	C	5.6	Single (VV)	26	35
RADARSAT 1	1995-2013	C	5.6	Single (HH)	8–100	3-24
ENVISAT/ ASAR	2002–2012	C	5.6	Single, Dual	30-1000	35
ALOS/ PALSAR	2006–2011	L	23.6	Single, Dual, Quad	10–100	46
RADARSAT 2	2007–	C	5.6	Single, Dual, Quad	3–100	24
TerraSAR-X TanDEM-X	2007– 2010–	X	3.1	Single, Dual, Interfero-metric	1–16	11

Past, current, and future SAR missions (2/2)

Satellites/ sensors	Period of operation	Band	Wave-length (cm)	Polarisation	Spatial resolution (m)	Orbital repeat (days)
COSMO-SkyMed	2007–	X	3.1	Single, Dual	1–100	16
RISAT-1	2012–	C	5.6	Single, Dual, Quad	1–50	25
ALOS-2/ PALSAR-2	2014–	L	23.8	Single, Dual, Quad	1–100	14
Sentinel-1A Sentinel-1B	1A: 2014– 1B: scheduled 2015	C	5.6	Single, Dual, Quad	91–5	12
SAOCOM-1A SAOCOM-1B	Scheduled 2015, 2016	L	23.5	Single, Dual, Quad	101–00	16
NovaSAR	Scheduled 2015	S	9.4	Single, Dual, Triple, Quad	6–30	14
RADARSAT Constellation 1/2/3	Scheduled 2018	C	5.6	Single, Dual, Quad	1–100	12
BIOMASS	Scheduled 2020	P	69.0	Quad	50	Varying

SAR data capabilities for forest cover monitoring and biomass estimation

- SAR data useful in heavy cloud and rain-affected regions
- SAR provides complementary information to optical data on forest/land use cover
- Opportunities for improved forest monitoring and biomass estimation through integration of SAR, optical and LIDAR
- SAR capacity demonstrated at subnational and regional levels

SAR capabilities for forest monitoring

- **L-band SAR**: demonstrated potential for **forest cover and change monitoring** using time-series dual polarization data (cross-pol most sensitive to forest structure)
- Use of *JERS-1* to generate a **historic baseline**, against which forest cover change can be monitored using more recent ALOS PALSAR (and ongoing monitoring using ALOS-2)
- **C-band** (R&D): dense time-series of observations typically required for accurate detection of **forest cover change**
- **X-band** (R&D): application in **forest degradation assessment**, e.g., selective logging where partial or complete removal of canopy can be detected; also **forest height** estimation using TanDEM-X

SAR capabilities for biomass estimation (1/2)

- Approaches to AGB estimation: model-based inversion and canopy height retrieval
- InSAR technique to retrieve canopy height, combined with allometrics and ground data to estimate biomass
- Signal saturation:
  - C-band: < 50t/ha
  - L-band: up to 100t/ha
  - P-band: > 300t/ha
  - combination with optical: up to 400t/ha
- Combination of different polarizations (e.g., C-HV/C-HH ratio) can improve biomass estimates

SAR capabilities for biomass estimation (2/2)

- SAR-based retrieval may be affected by terrain, rainfall, soil moisture, localized algorithm development, saturation levels
- Calibration of algorithms requires reliable ground data
- SAR AGB retrieval has been more successful in temperate and boreal forests compared to tropical forests (fewer species, lower biomass)
- **Multisensor approaches** (SAR-LiDAR, SAR-LiDAR-Optical) are promising (demonstrated in the United States, Amazon, Australia, Nepal, Borneo)
- Biomass change estimation:
    - Two observations in time to model change
    - Modelling biomass for each time and take difference

SEPAL Data Integration

- Combining datasets for:
- Forest / non-forest
- Change detection
- Biomass
- Example country: Zambia

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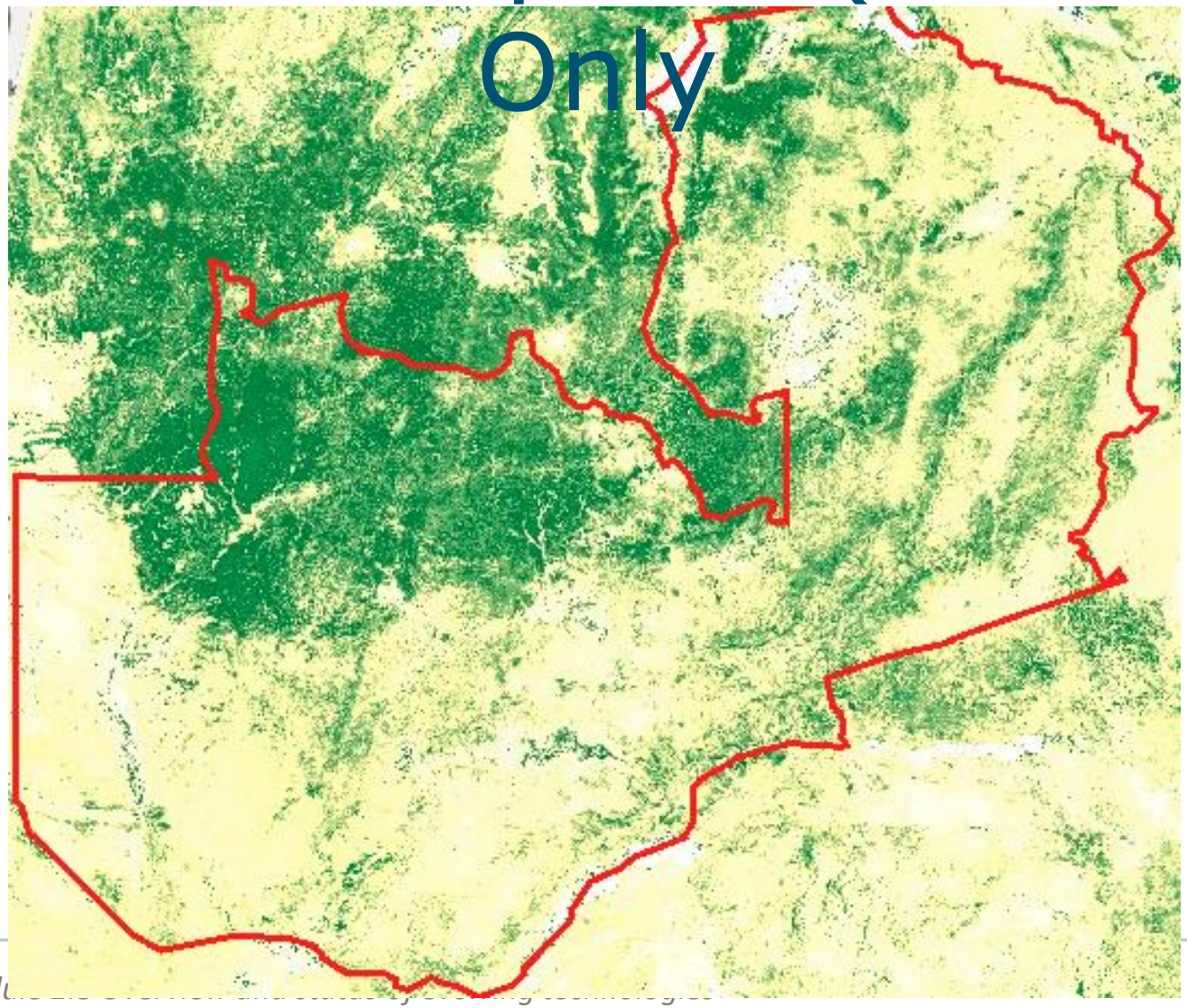
Biomass - Optical (Landsat) Only



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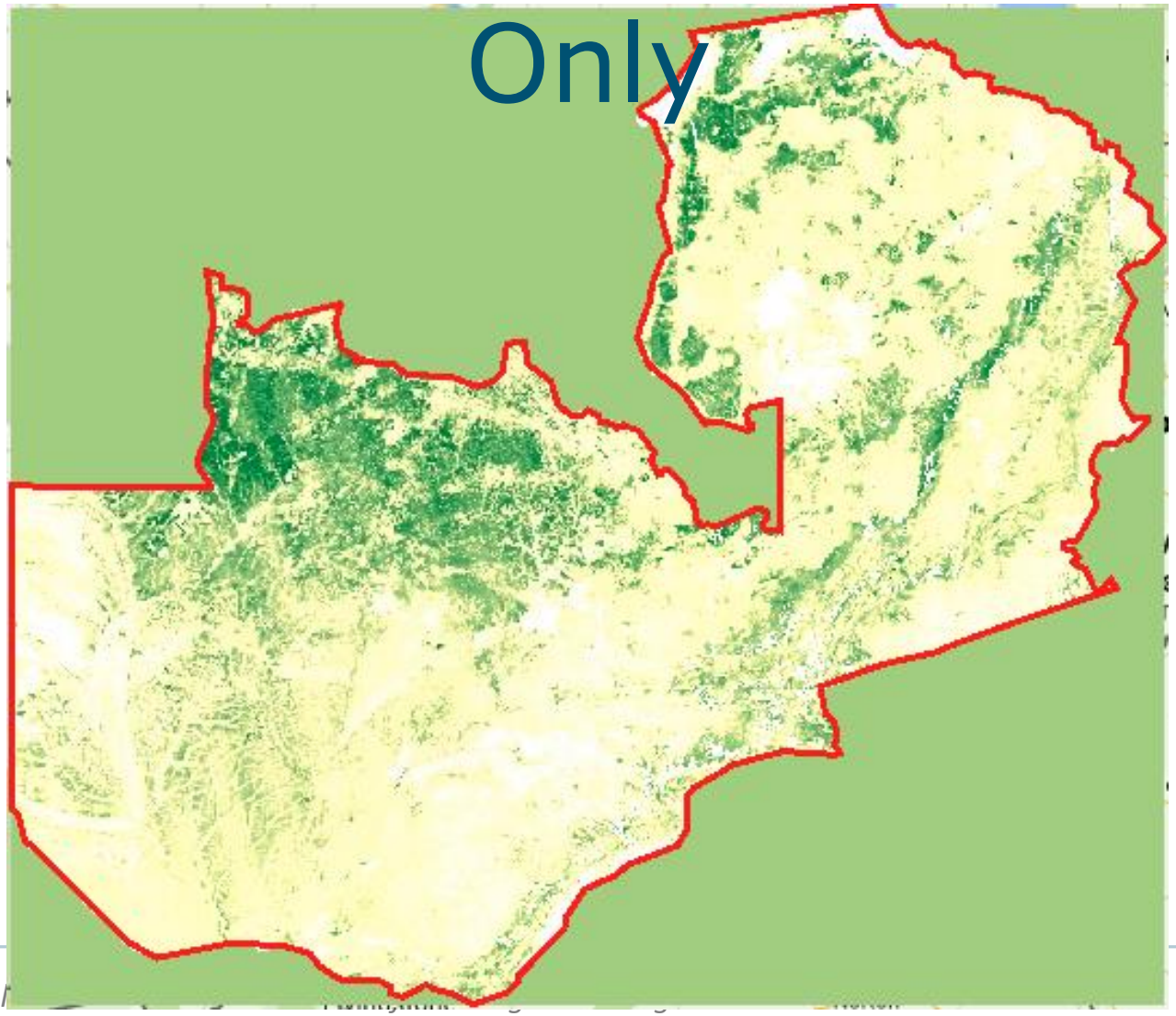
Biomass - RADAR (ALOS) Only



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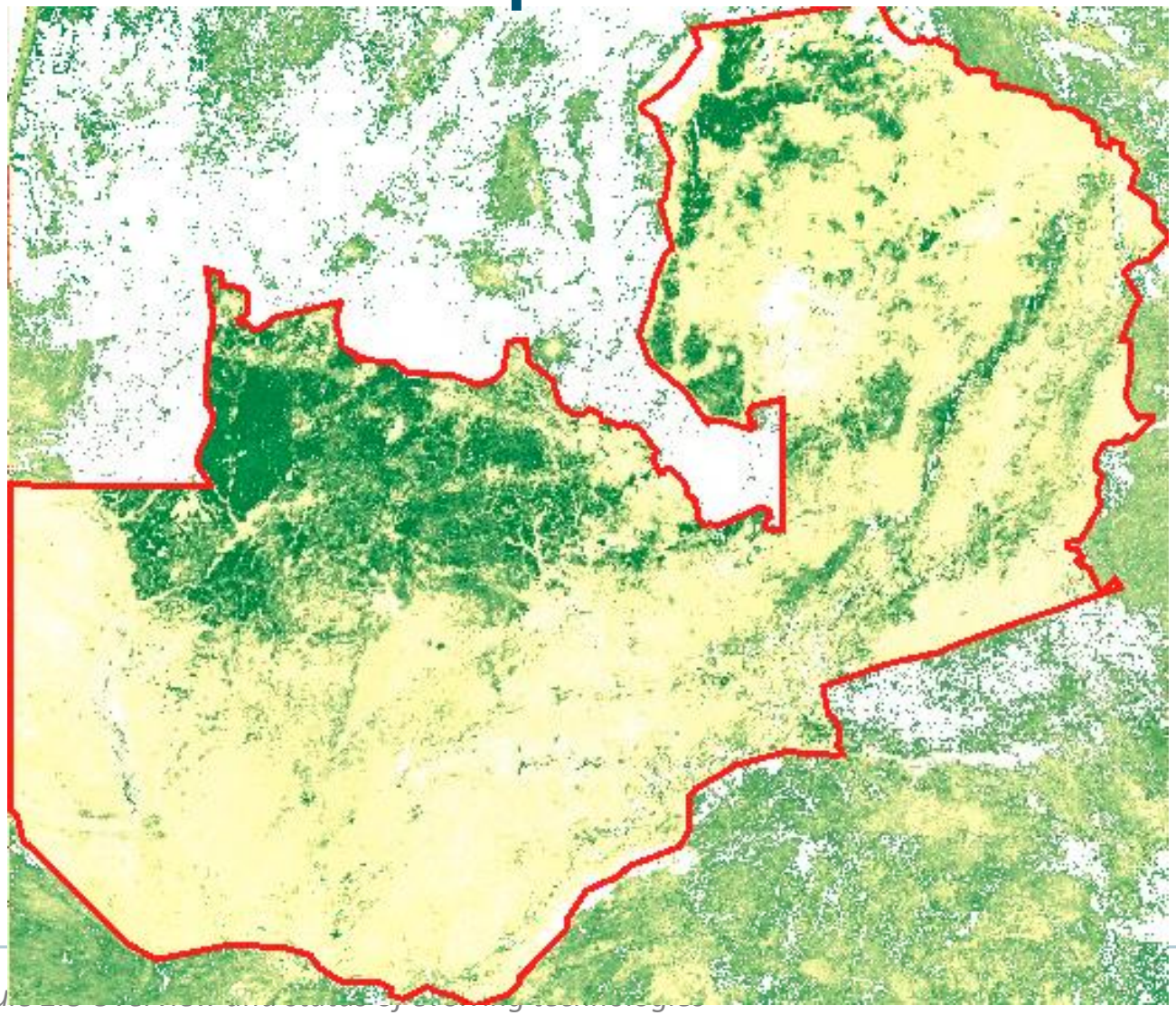
Biomass - Optical + RADAR



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Applicability of radar for forest monitoring

Technical capabilities of remote sensing sensors for the generation of (national) REDD+ information products

Forest information product	Sensor type						
	Optical/thermal			Radar/SAR		LiDAR	
	Coarse	Medium	Fine	Medium	Fine	Satellite (Large footprint[a])	Airborne (Small footprint[a])
Forest area change monitoring	Contributing	Very suitable	Very suitable	Suitable	Suitable	Limited to no technical capabilities	Contributing
Near real-time deforestation detection	Suitable	Suitable	Limited to no technical capabilities	Contributing	Limited to no technical capabilities	Limited to no technical capabilities	Limited to no technical capabilities
Land use change patterns and tracking of human activities	Contributing	Very suitable	Very suitable	Suitable	Contributing	Limited to no technical capabilities	Limited to no technical capabilities
Forest degradation monitoring	Limited to no technical capabilities	Suitable	Very suitable	Contributing	Suitable	Limited to no technical capabilities	Suitable
Monitoring of wildfires and burnt areas	Suitable	Suitable	Contributing	Contributing	Contributing	Limited to no technical capabilities	Contributing
Biomass mapping	Contributing	Contributing	Suitable	Suitable	Suitable	Suitable	Very suitable
Sub-national hotspot monitoring	Contributing	Suitable	Very suitable	Limited to no technical capabilities	Suitable	Limited to no technical capabilities	Suitable
Forest type mapping	Limited to no technical capabilities	Contributing	Very suitable	Limited to no technical capabilities	Suitable	Limited to no technical capabilities	Very suitable

[a]Footprint is the ground instantaneous field-of-view, which is a measure of the ground area viewed by a single detector element in a given instant in time.

- Very suitable
- Suitable
- Contributing
- Limited to no technical capabilities

De Sy et al. 2012.

In summary

- Radar is an **active system** based on the principles of radar reflectivity: backscattering of canopy, volume, and surface.
- Radar sensors operate in the **microwave region** and are able to penetrate through clouds.
- System parameters and surface conditions influence backscattered energy intensity.
- **Preprocessing** is needed to remove geometric distortions such as foreshortening and layover, topographic effects, and speckle noise.
- Currently operational SARs systems operate in wavelengths from **X-, C- to L-bands** with different functionalities.
- Opportunities for **improved forest monitoring** and **biomass estimation** exist through integration of SAR, optical, and LIDAR.