Module 2.8 Overview and status of evolving technologies

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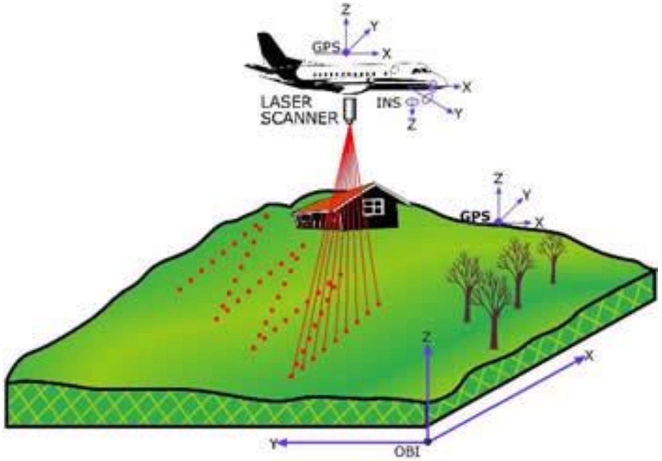
After the course the participants should be able to:

- 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

V2, February 2017

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GOFC-GOLD
Global Observation of Forest and Land Cover Dynamics

FOREST CARBON PARTNERSHIP FACILITY

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

Outline of lecture

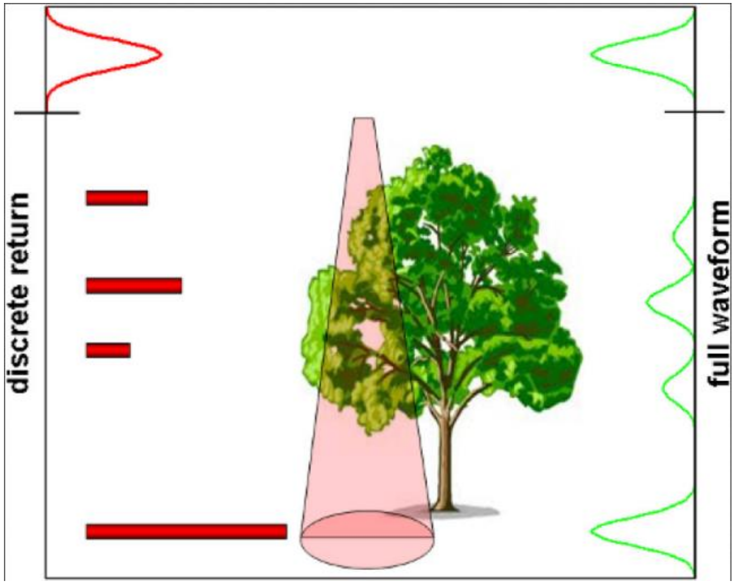
1. **Role of LIDAR observations for forest characterization and experiences with LIDAR for monitoring purposes**
2. The use of RADAR for forest monitoring

Background material LIDAR

- GOFC-GOLD Sourcebook, 2014. Section 2.10 http://www.gofcgold.wur.nl/redd/index.php
- GFOI MGD, 2014. Sections 3.2.4 and 3.2.5 http://www.gfoi.org/methods-guidance-documentation
- De Sy, V., Herold, M., Achard, F., Asner, G.P., Held, A., Kellndorfer, J., and Verbesselt, J. (2012) Synergies of multiple remote sensing data sources for REDD+ monitoring. Current Opinion in Environmental Sustainability. 1-11.
- McRoberts, R.E., Andersen, H.-E., & Næsset, E. (2014). Using airborne laser scanning data to support forest sample surveys. In: Maltamo, M., Næsset, E., & Vauhkonen, J. (Eds.). Forestry applications of airborne laser scanning. Springer.
- McRoberts, R.E., Bollandsås, O.M. (2014). Modeling and estimating change. In: Maltamo, M., Næsset, E., & Vauhkonen, J. (Eds.). Forestry applications of airborne laser scanning.
- Næsset E. (1997) Estimating timber volume of forest stands using airborne laser scanner data. Remote Sens Environ 51: 246-253.
- Vauhkonen, J., Maltamo, M., McRoberts, R.E., & Næsset, E. (2014). Introduction to forest applications of airborne laser scanning. In: Maltamo, M., Næsset, E., & Vauhkonen, J. (Eds.). Forestry applications of airborne laser scanning. Springer.

LIDAR: Background and characteristics

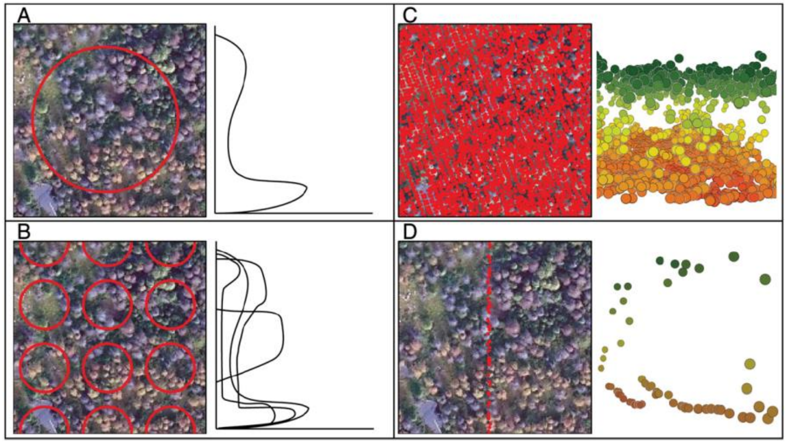
- LIght Detection And Ranging (LIDAR) technology uses **active sensors**
- Information obtained from lasers to estimate the **three-dimensional distribution** of vegetation canopies as well as subcanopy topography
- LIDAR systems classified as either **full waveform** or **discrete return** sampling 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)

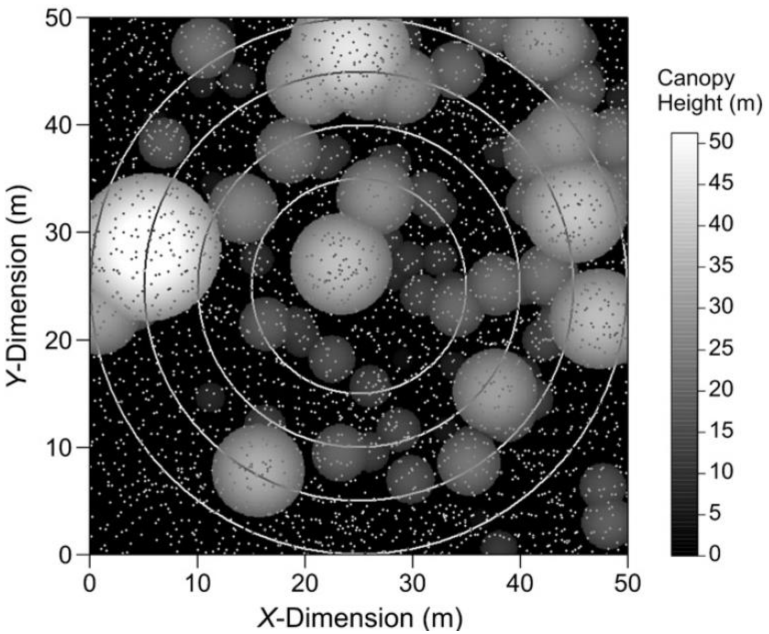
- **Height estimates** obtained from airborne remotely sensed LIDAR data have similar or better accuracy than field-based estimates
- LIDAR measurement errors can be < 1.0 m for individual tree heights of a given species
- **LIDAR** measurements have no saturation effect
- **Ground measurements required** 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

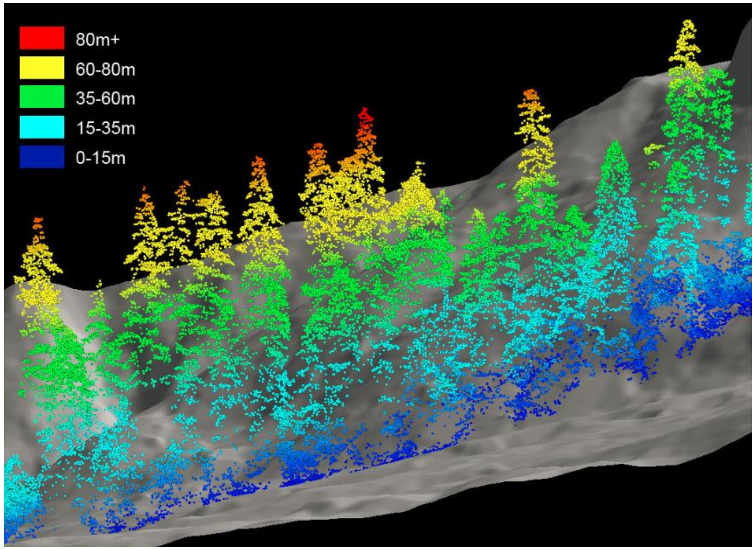


Photo credit: Spies and Olsen, Oregon State U.

Design, modelling, and estimation for LIDAR survey (1/5)

- **Models** based on relationships between forest attributes and LIDAR data commonly constructed using combination of **field plot observations** and **geo-referenced LIDAR metrics**
- Little empirical information on plot configurations and sampling designs available
- Results for boreal and temperate forest studies may not be definitive for tropical applications, but may provide useful guidance on:
  - GPS location accuracy
  - Positional error

Design, modelling, and estimation for LIDAR survey (2/5)

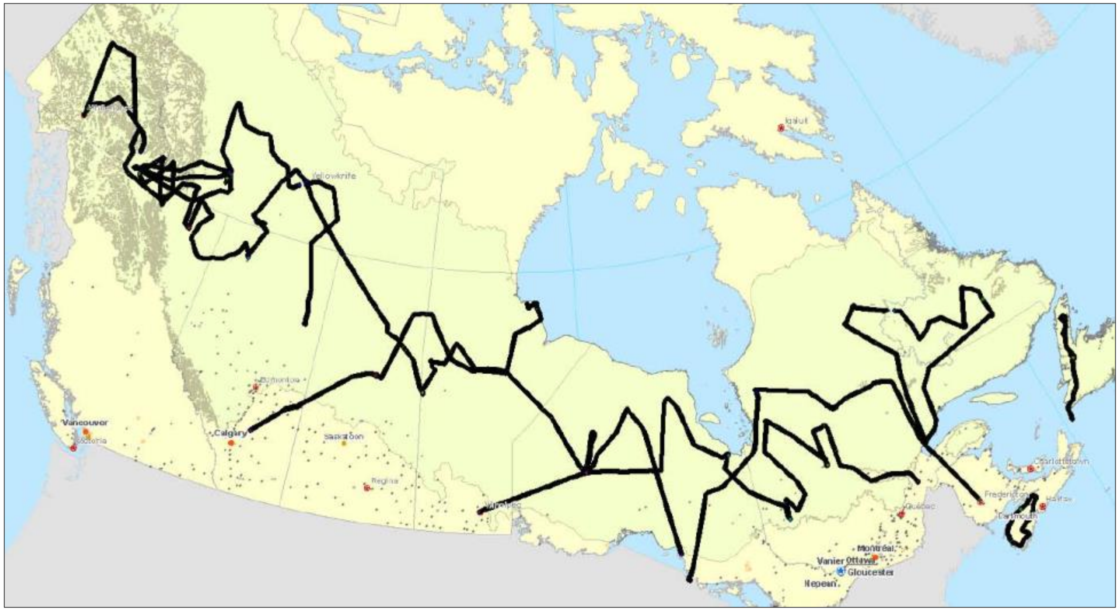
- Plot shape:
  - Boreal and temperate forests: Circular plots
  - Tropical countries: rectangular plots
- Pulse densities:
  - Boreal and temperate forests: >0.1 pulses/m^2; plot areas >200 m^2; pulse densities 100-225 per plot
  - May be minimum thresholds for tropical countries
- Ground sampling:
  - Expensive
  - Capitalize on existing sampling programs (e.g., national forest inventories) to acquire ground training and accuracy assessment data

Design, modelling, and estimation for LIDAR survey (3/5)

- LIDAR strips can be designed based on systematically distributed ground plots (e.g., from national forest inventories)
- Strips may be also either randomly or systematically distributed over the study area, and the ground plots may be established exclusively within the LIDAR swaths

Design, modelling, and estimation for LIDAR survey (4/5)

- Combinations of the scenarios are possible
- Yield of data along the transects may also be modulated to mitigate spatial autocorrelation of measures



Credit: Natural Resources Canada.

Design, modelling, and estimation for LIDAR survey (5/5)

- **Stratified random sampling using strata** (e.g., heights, coarser biomass map):
  - Can produce smaller RMSEs (root mean square error) between biomass and LIDAR metrics
  - Requires fewer extrapolations beyond range of LIDAR sample data when the model applied to entire population
- **Confidence intervals** for the LIDAR-based estimates for large areas necessary in addition to **map accuracy** measures for categorical forest attribute variables or model RMSE for continuous variables
- See Module 2.7. on estimation of uncertainties

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)
- In 2018 GEDI and ICESat-2 spaceborne missions will be launched
- 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, participation of national agencies may be required
- Airborne data can be collected by a variety of instruments, over a range of settings, resulting in data with varying qualities

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	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.

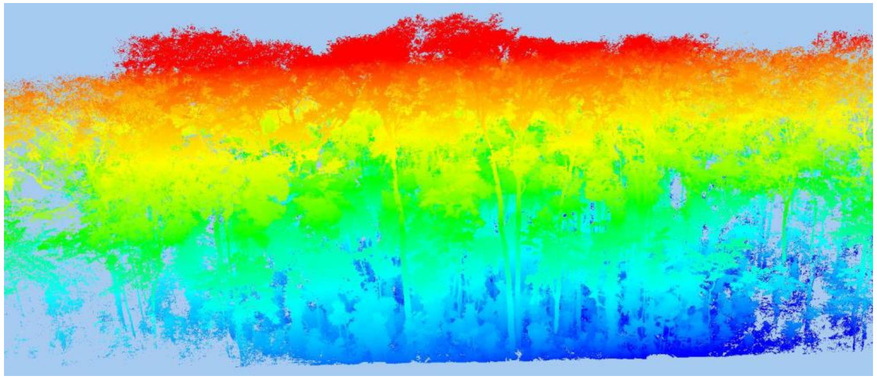
- Very suitable
- Suitable
- Contributing
- Limited to no technical capabilities

De Sy et al. 2012.

Terrestrial LIDAR (1/5)

- Also known as Terrestrial Laser Scanning (TLS)
- Ground-based remote sensing system that can measure 3D vegetation structure
- Records scans from a fixed location
- Possibility to estimate parameters such as tree height, DBH, volume, above ground biomass, canopy closure

A 3D TLS point cloud



Calders et al., in REDD Sourcebook, 2015

Terrestrial LIDAR (2/5)

Overview of commonly used commercial TLS instruments

Instrument	RIEGL-VZ400	Leica C10	Leica HDS7000	Optech ILRIS-HD	FARO Focus^{3D} X 330	Trimble TX8
Ranging method	Time-of-flight	Time-of-flight	Phase-shift	Time-of-flight	Phase-shift	Time-of-flight
# returns	Multiple	Single	Single	Single	Single	Single
Wavelength [nm]	1550	532	1500	1535	1550	1500
Range [m]	0.5 – 350 (high speed) 0.5 – 600 (long range)	0.1-300	0.3-187	3 – 1250	0.6 - 330	0.6 - 120
Samples/sec	42,000–122,000	50,000	101,6000	10,000	122,000-976,000	1,000,000
Beam Divergence [mrad]	0.3	0.1	< 0.3	0.150	0.19	0.177
Weight [kg]	9.6	13	10	14	5.2	11
Temperature range [deg C]	0 - 40	0-40	0-45	-20 – 40	5 – 40	0-40

Calders et al., in REDD Sourcebook, 2015

Terrestrial LIDAR (3/5)

Status and outlook

- TLS estimates of forest properties have been shown to be of higher-accuracy than traditional survey methods, particularly tree height.
- More practical methods of acquiring and processing TLS data needed to develop use of TLS
- Relationship between gap probability and significant structural metrics is empirical and not well understood
- Current geometric modelling methods provide clear, detailed and accurate characterization of structure on individual tree, but more development required to automate algorithms to provide efficient plot level based estimates

Terrestrial LIDAR (4/5)

Status and outlook

- TLS data have potential to provide volume information at a fraction of the cost of traditional destructive methods
- TLS likely to reduce uncertainty of the resulting AGB values compared with allometric methods that underpin all current field-based and satellite-derived AGB estimates.

Terrestrial LIDAR (5/5)

References

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Calders, K., Armston, J., Newnham, G., Herold, M. and Goodwin, N. (2014) Implications of sensor configuration and topography on vertical plant profiles derived from terrestrial LiDAR. Agricultural and Forest Meteorology 194: 104-117.

Calders, K., Newnham, G., Burt, A., Murphy, S., Raumonen, P., Herold, M., Culvenor, D., Avitabile, V., Disney, M., Armston, J. and Kaasalainen, M. (2015), Nondestructive estimates of above-ground biomass using terrestrial laser scanning. Methods Ecol Evol, 6: 198–208.

Jupp, D. L. B., Culvenor, D. S., Lovell, J. L., Newnham, G. J., Strahler, A. H. and Woodcock, C. E. (2009). Estimating forest lai profiles and structural parameters using a ground-based laser called echidna. Tree physio

Newnham, G., Armston, J., Muir, J., Goodwin, N., Tindall, D., Culvenor, D., Puschel, P., Nystrom, M., & Johansen, K. (2012). Evaluation of terrestrial laser scanners for measuring vegetation structure. CSIRO Sustainable Agriculture Flagship.

Ni-Meister, W., Lee, S., Strahler, A. H., Woodcock, C. E., Schaaf, C., Yao, T., Ranson, K. J., Sun, G. and Blair, J. B. (2010). Assessing general relationships between aboveground biomass and vegetation structure parameters for improved carbon estimate from lidar remote sensing. Journal of Geophysical Research, 115: G00E11.

In summary

- LIDAR technology uses active sensors
- LIDAR sensors can estimate tree/stand height, volume, biomass, forest structure, 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**

Background material RADAR

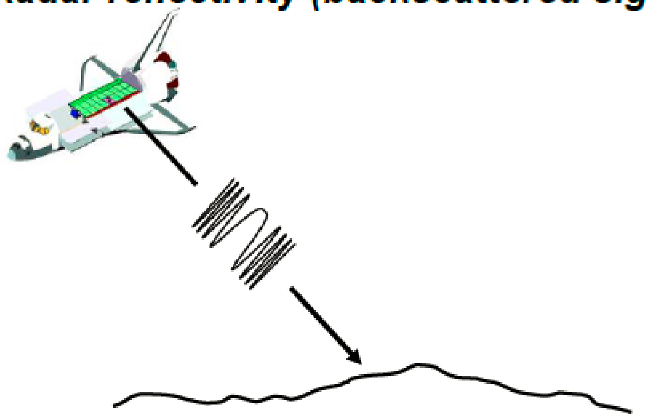
- De Sy, V., Herold, M., Achard, F., Asner, G.P., Held, A., Kellndorfer, J., and Verbesselt, J. (2012) Synergies of multiple remote sensing data sources for REDD+ monitoring. Current Opinion in Environmental Sustainability. 1-11.
- GOFC-GOLD Sourcebook section 2.10 http://www.gofcgold.wur.nl/redd/index.php
- Gibbs HK, Brown S, Niles JO, Foley JA (2007) Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environ Res Lett, 2:045023. Synthesizes options to estimate national-level forest biomass carbon stocks in developing countries and proposes methods to link forest carbon and deforestation estimates.
- Sarker, L. R., Nichol, J., & Mubin, A. (2013). Potential of Multiscale Texture Polarization Ratio of C-band SAR for Forest Biomass Estimation. In A. Abdul Rahman, P. Boguslawski, C. Gold, & M. N. Said (Eds.), *Developments in Multidimensional Spatial Data Models* (Springer., pp. 69–83). Berlin, Heidelberg: Springer Berlin Heidelberg. doi:10.1007/978-3-642-36379-5.

Synthetic Aperture Radar (SAR) technology

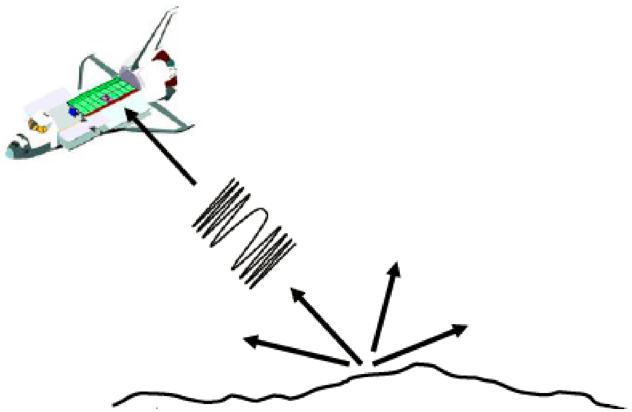
- SAR sensors used since the 1960s to produce images of earth-surface based on the principals of **radar** (radio detection and ranging) **reflectivity**
- SAR based on relative motion between sensor's antenna and target: implemented using usually a **moving platform** (aircraft, space shuttle, satellite)
- 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***



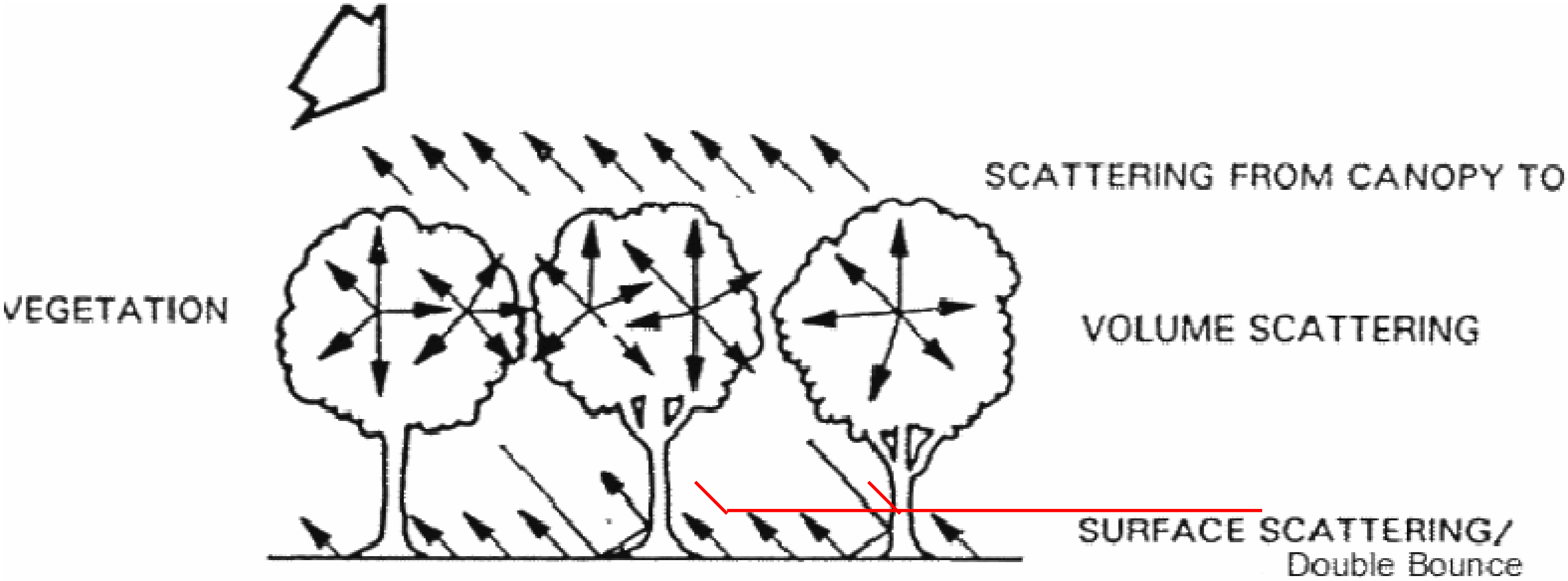
- Radar transmits a pulse (travelling velocity is equal to velocity of light)



- 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.

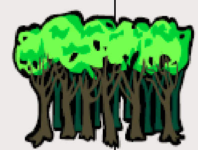
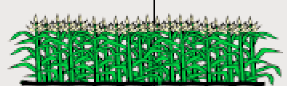
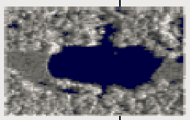
Radar backscattering mechanisms (2/3)



Source: Thiel 2011.

Radar backscattering mechanisms (3/3)

Backscattering Coefficient σ_o

Levels of Radar backscatter		*Typical scenario*
• *Very high backscatter (above -5 dB)*		*Man-Made objects (urban)* *Terrain Slopes towards radar* *very rough surface* *radar looking very steep*
• *High backscatter (-10 dB to 0 dB)*		*rough surface* *dense vegetation (forest)*
• *Moderate backscatter (-20 to -10 dB)*		*medium level of vegetation* *agricultural crops* *moderately rough surfaces*
• *Low backscatter (below -20 dB)*		*smooth surface* *calm water, road* *very dry terrain (sand)*

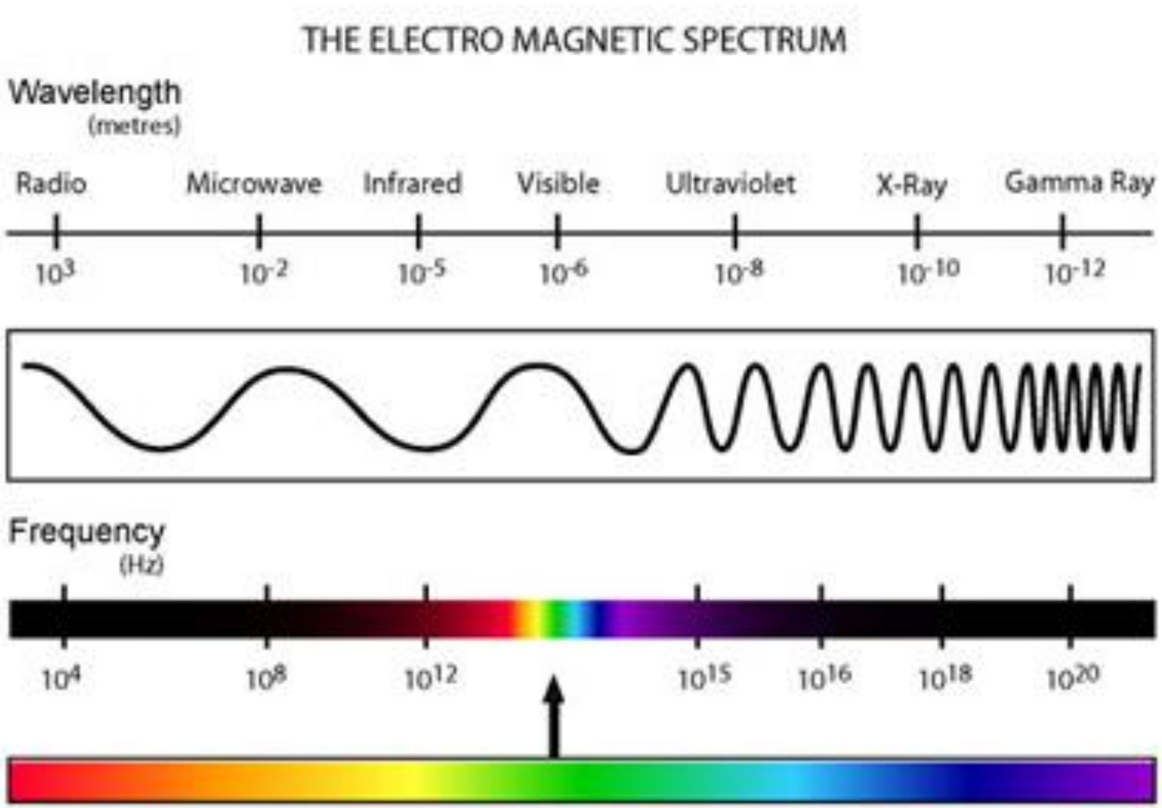
Source: Lopez-Dekker 2011.

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

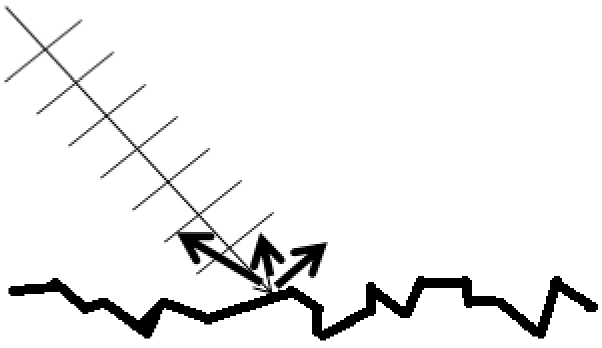
Synthetic aperture radar (SAR) technology

- Microwaves penetrate into forest canopies, amount of backscattered energy intensity dependant in part on:
  - System parameters
    - incidence angle
    - wavelength
    - polarisation
  - Surface conditions
    - roughness
    - geometric shape
    - dielectric properties of the target

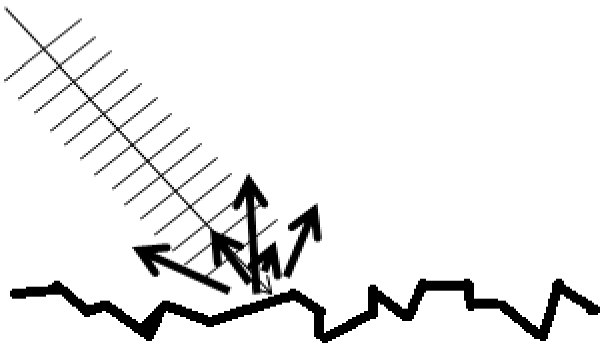
=> Backscatter signal provides useful information on forest structural attributes including structural forest cover type and aboveground biomass

Surface roughness

- Backscattered energy intensity generally increases with surface roughness, *for a given wavelength.*



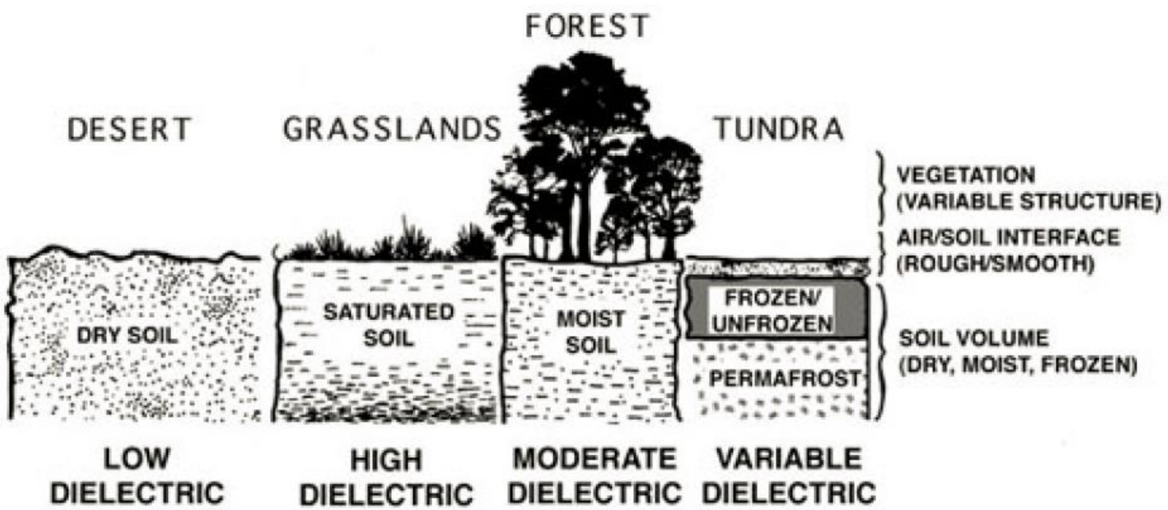
The surface appears smooth to long wavelength
=> Backscattering is low



The surface appears rough to shorter wavelength
=> Backscattering increases

Dielectric constant

- Controlled by moisture content of the target
- Varies commonly between 1 and 100,
  e.g., dry natural materials: 3-8; water: 80
- Radar backscatter is influenced by amount of moisture in vegetation and soil
- Increased moisture reduces penetration of the radar signal



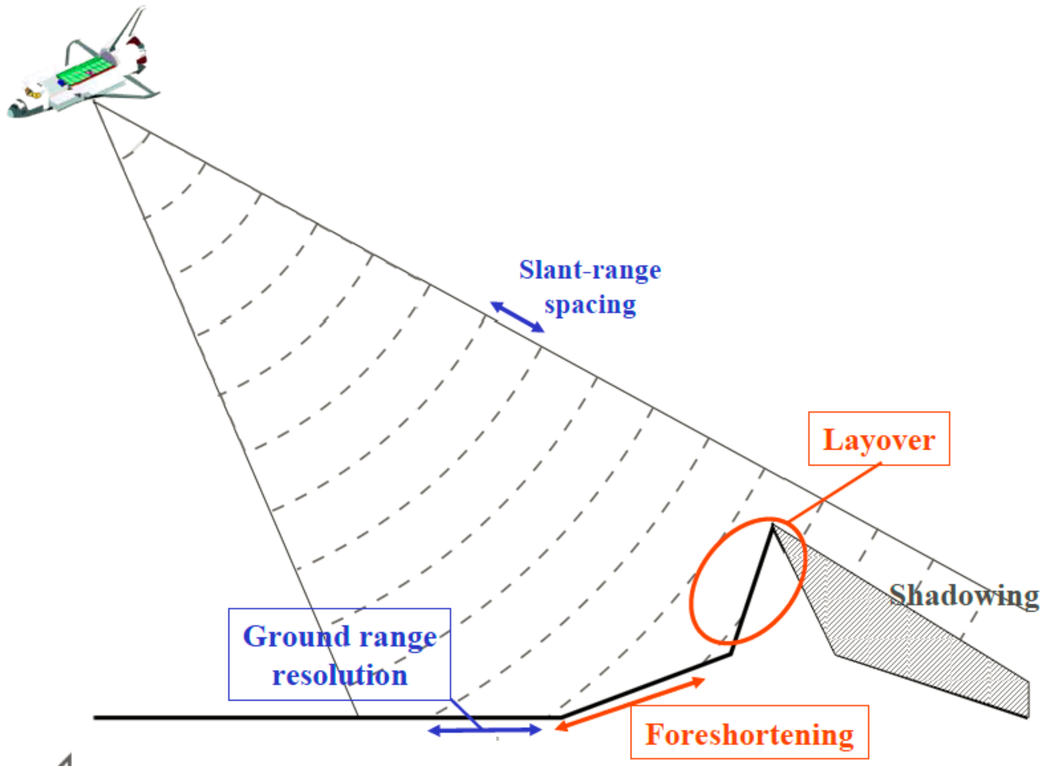
Source: Walker n.d.

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

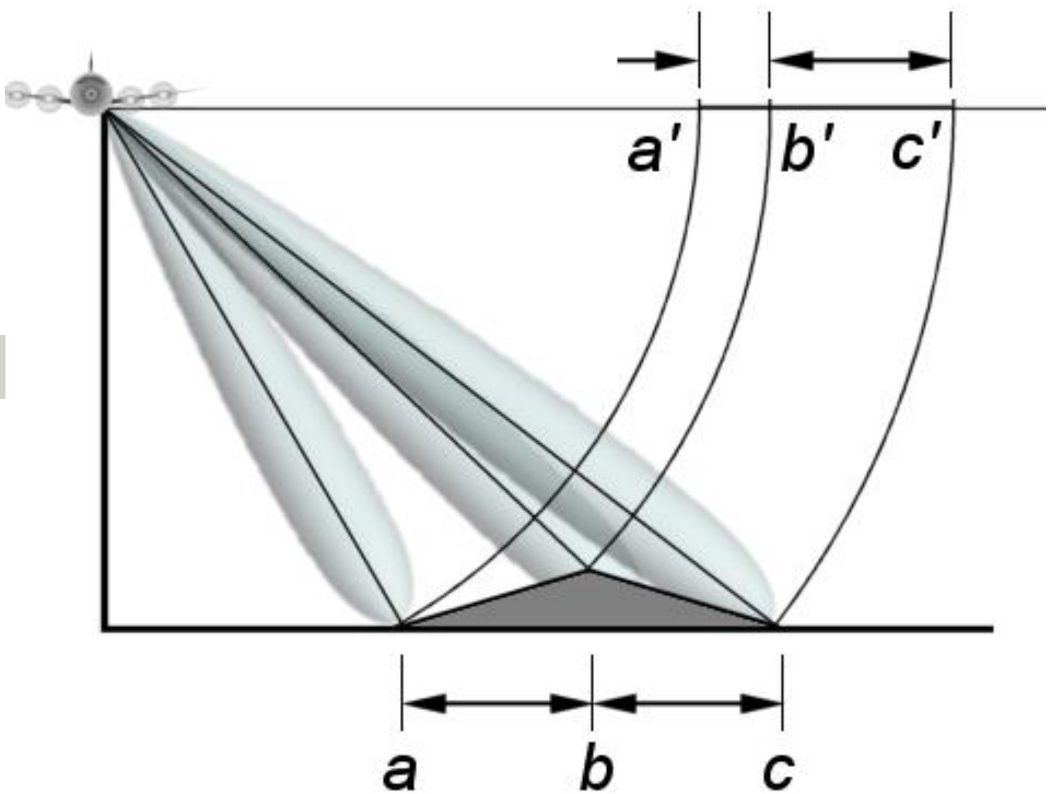
Geometric distortions (1/3)



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

Geometric distortions (2/3)

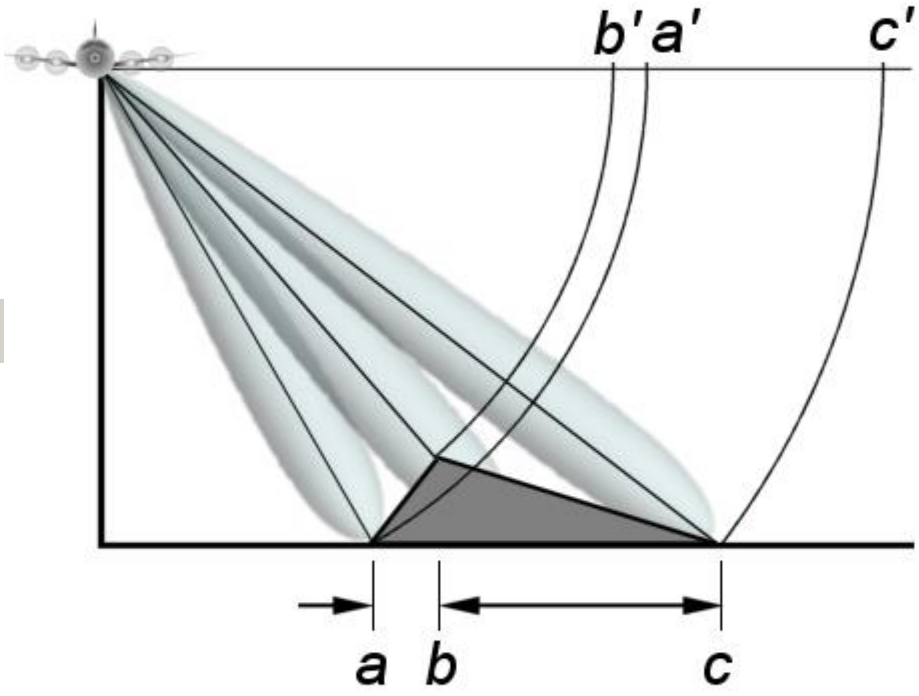
Foreshortening



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

Geometric distortions (3/3)

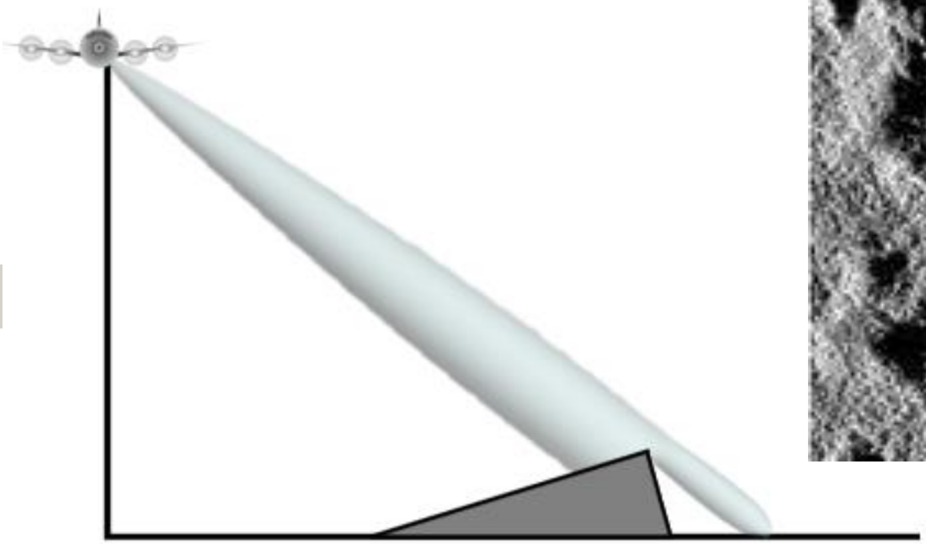
Layover



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

Topographic effects

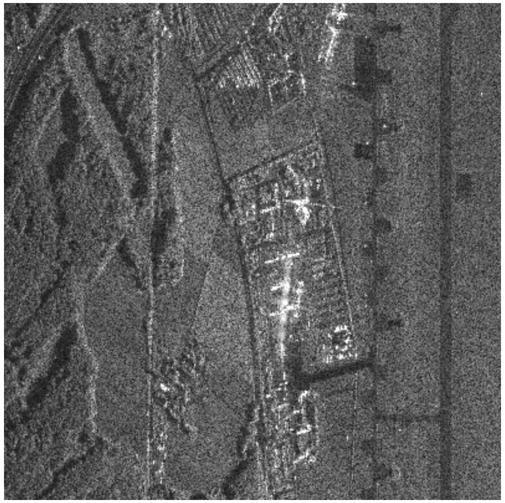
Shadowing



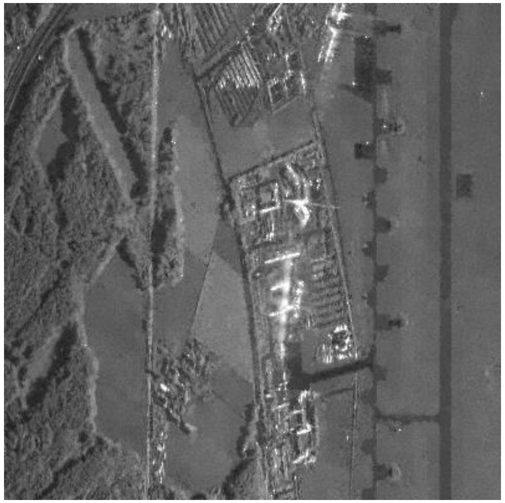
Source: Radiotutorial n.d., http://www.radartutorial.eu/20.airborne/ab07.en.html.

Preprocessing of radar signal (cont'd)

- Speckle noise affects radar images, reducing class spectral seperability
- Results from random fluctuations in the return signal from an object
- Preprocessing required to filter the images minimizing loss of information



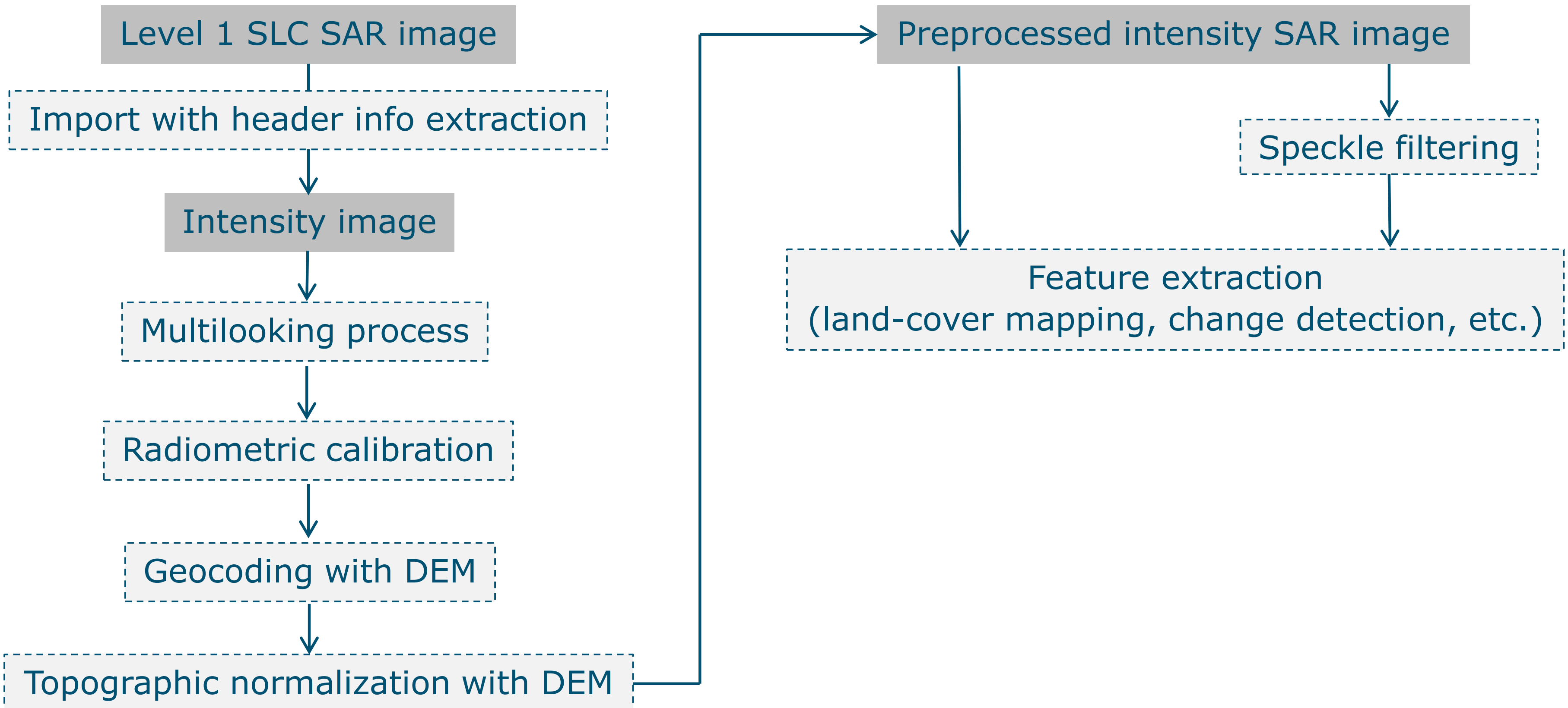
original SAR image
Airborne SAR AeS-1



speckle filtered
Model based approach

Source: Lopez-Dekker, 2011

Preprocessing chain

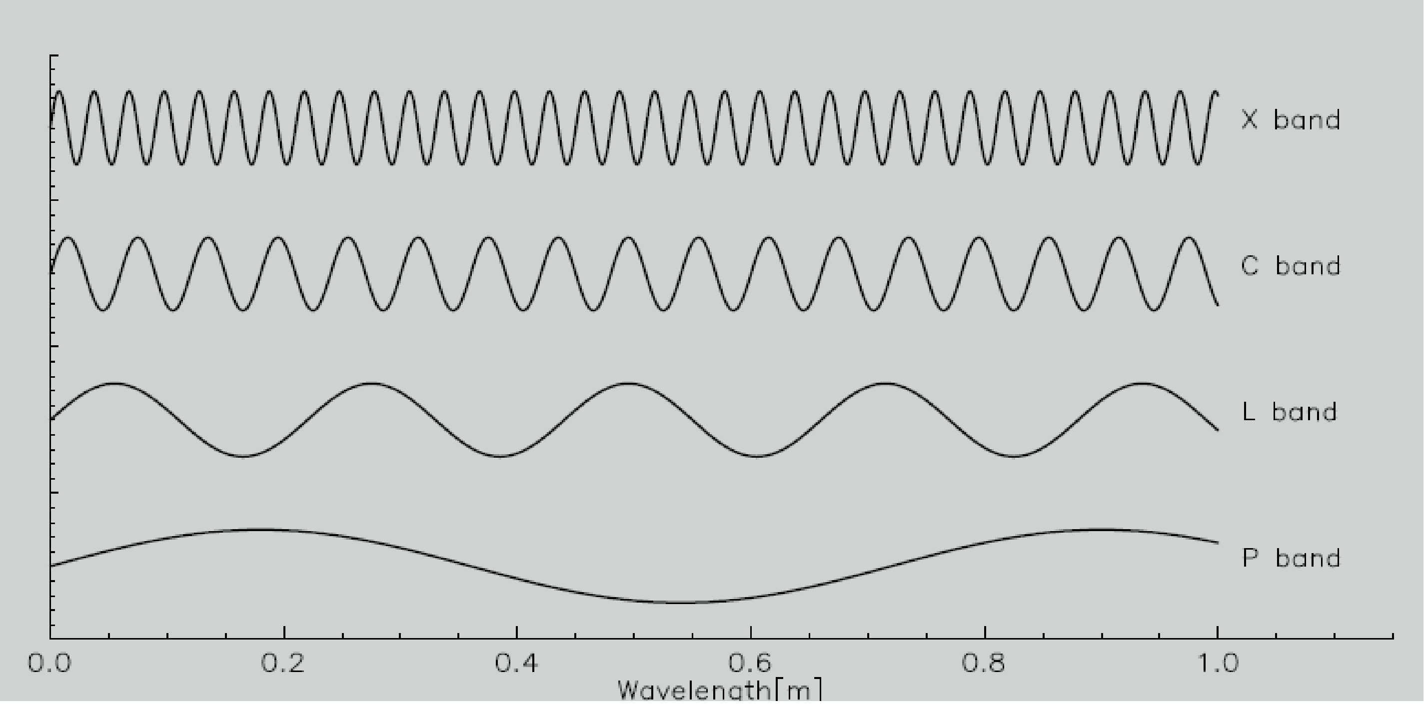


Radar band characteristics (1/4)

- 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

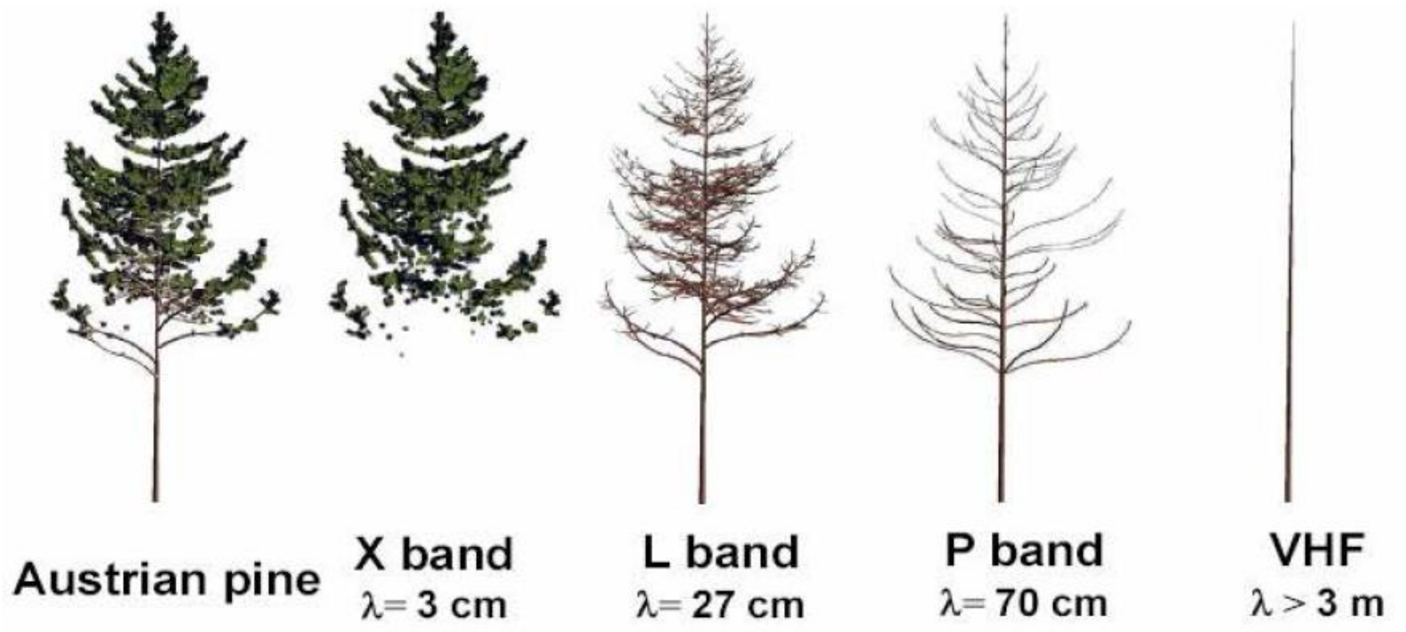
Band	Typical frequency (GHz)	Wave-length (cm)
P	0,350	85
L	1.3-1.4	23-21
C	5.3-5.4	5.6-5.5
X	9.65	3.1
Ku	12-18	2.5-1.6
Ka	35	0.8

Radar band characteristics (2/4)



Source: Lopez-Dekker 2011.

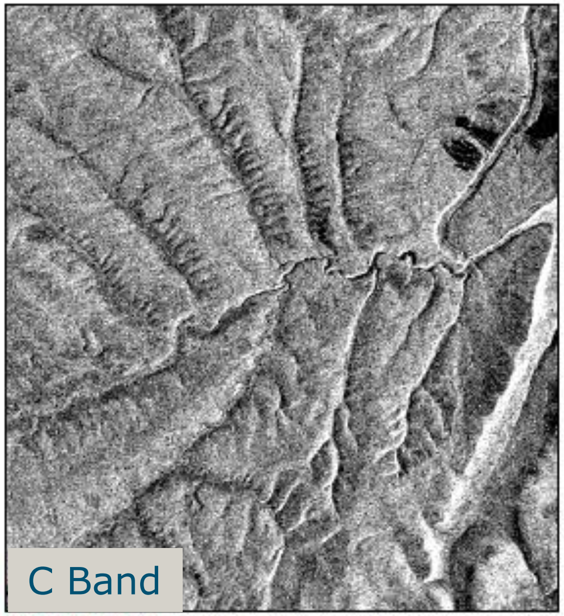
Radar band characteristics (3/4)



Credit: Le Toan.

Radar band characteristics (4/4)

Forest at different frequencies



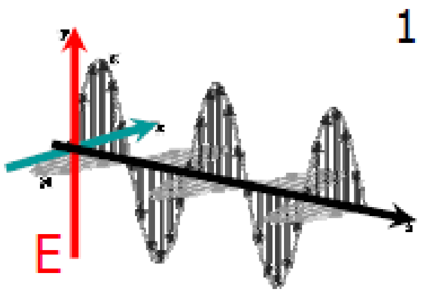
- Small dynamic range
- Variable response to water
- Variable response to open areas
- Can be used as indicator of environmental effects effecting the coherence

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

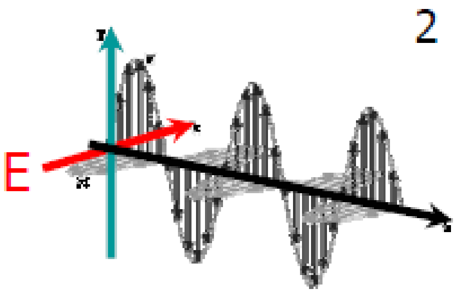
Source: Thiel 2011.

SAR techniques: Polarimetry

- Radar waves have polarization
- Anisotropic materials can reflect waves at different polarizations and intensities
- Some material can convert a(n) (incoming) polarization into another one (returning)
- Multiple images can be generated from the same series of pulses



Vertical polarization



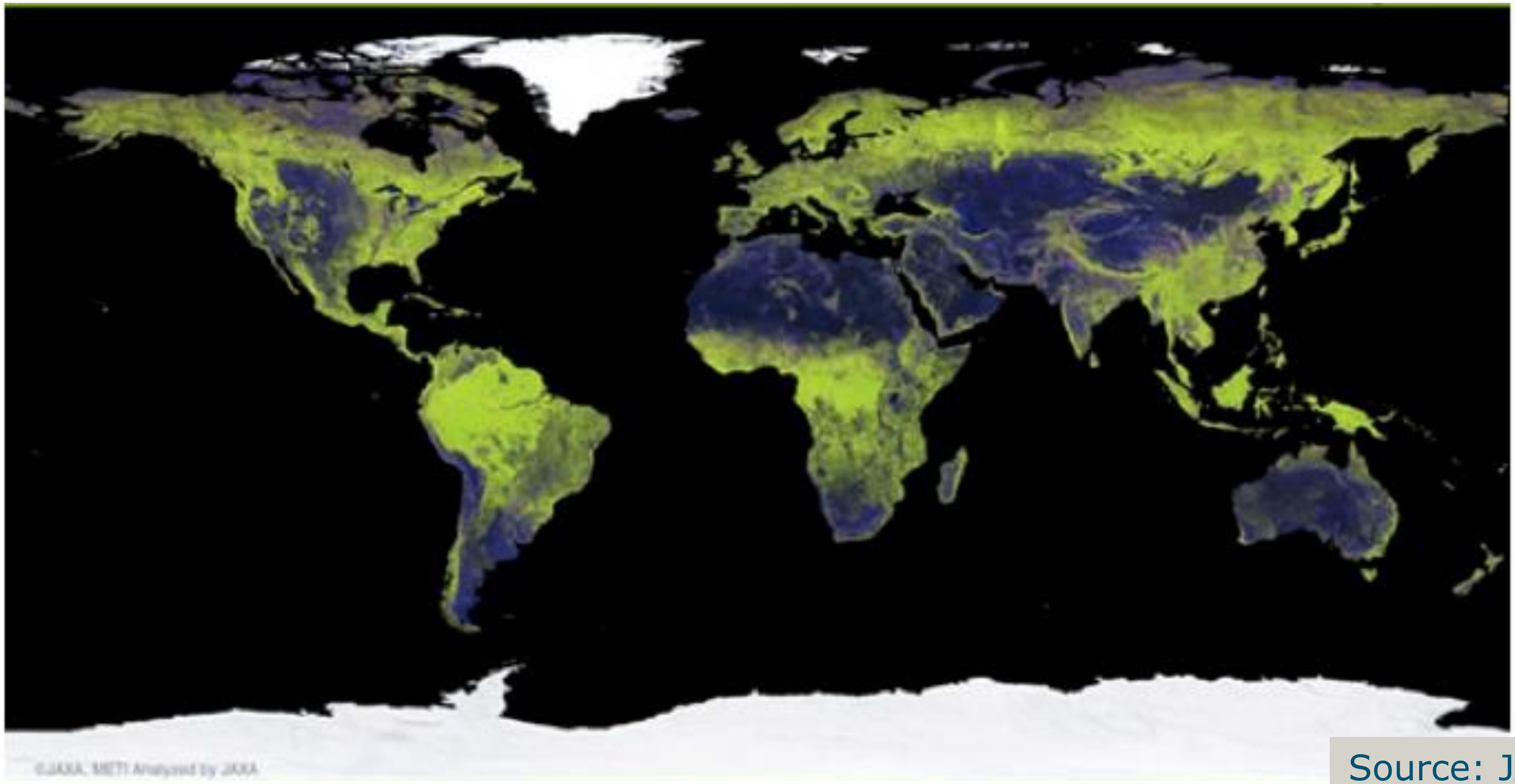
Horizontal polarization

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 (1/3)

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 (2/3)

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

Past, current, and future SAR missions (3/3)

Satellites/ sensors	Period of operation	Band	Wave-length (cm)	Polarisation	Spatial resolution (m)	Orbital repeat (days)
NISAR	Scheduled 2020	L, S	24 cm,12 cm	Pol	multiple	?
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 (1/2)

- **P-band SAR** (R&D): designed to provide information for forest biomass and height estimations (ESA BIOMASS mission to be launched in 2020)
- **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**

SAR capabilities for forest monitoring (2/2)

- **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

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.

Country examples

- Monitoring tropical deforestation in Kalimantan using radar
- Use of LiDAR and InSAR as auxiliary data to estimate forest biomass in a boreal forest area

Recommended modules and exercises as follow-up

- Modules 3.1 to 3.3 to proceed with REDD+ assessment and reporting

- Exercises available on: https://saredu.dlr.de/

Credits: ESA; GEO GFOI Method and Guidance Report (http://gfoi.org/)

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