LAND MANAGEMENT, ENVIRONMENT & SOLID-WASTE: INSIDE EDUCATION AND BUSINESS IN CENTRAL ASIA
ERASMUS-EDU-2023-CBHE Project Number: 101129032

MICRO-CREDENTIAL

LAND MANAGEMENT IN CENTRAL ASIA

14.- Radar and Laser Remote Sensing

Radar and Laser (LiDAR) Remote Sensing
PDF W14

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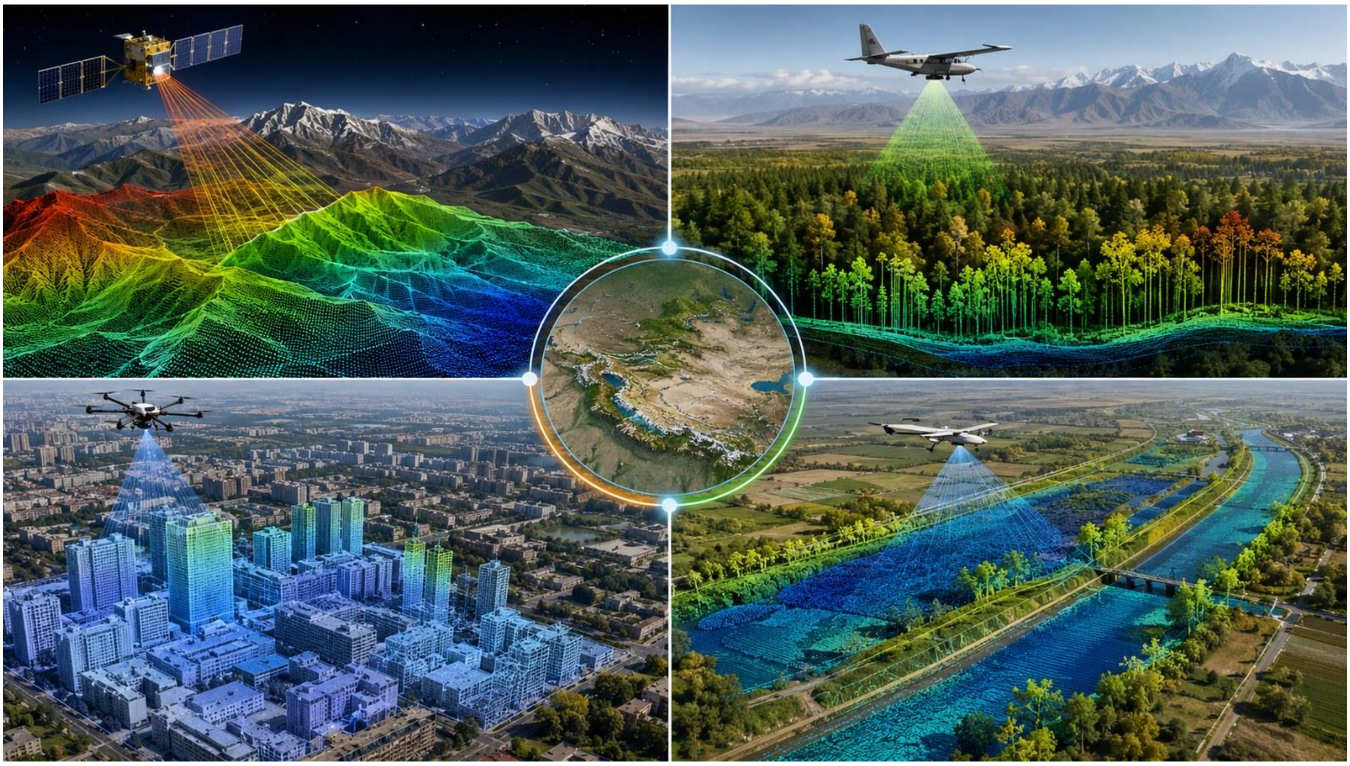

Conceptual visualisation: radar and LiDAR support 3D land, water and terrain analysis.

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1. SUMMARY OF KEY IDEAS

Radar and laser remote sensing are active observation methods. They do not depend only on sunlight; instead, the sensor sends energy toward the Earth and records the returned signal. Radar systems use microwave energy and are especially useful when clouds, haze, smoke, or night-time conditions limit optical observation. LiDAR systems use laser pulses and are especially powerful for creating detailed three-dimensional information about terrain, vegetation, buildings and infrastructure.

For land management, these systems are complementary. Radar is strong for monitoring surface roughness, soil moisture, flooded areas, wetland dynamics and ground deformation. LiDAR is strong for high-resolution elevation models, slope analysis, drainage mapping, canopy height, erosion assessment and engineering design. In Central Asian landscapes, where irrigation, salinity, mountain runoff, flood risk and land degradation are closely connected, the combined use of radar and LiDAR can improve evidence-based land and water decisions.

2. LEARNING OBJECTIVES

- Explain the difference between passive and active remote sensing systems.
- Describe the basic operating principles of radar, SAR, laser and LiDAR systems.
- Identify how wavelength, incidence angle, surface roughness, moisture and object structure influence radar and LiDAR observations.
- Interpret the main strengths and limitations of radar and LiDAR for land and water studies.
- Apply radar and LiDAR concepts to terrain analysis, flood mapping, irrigation monitoring and sustainable land management.

3. INTRODUCTION

Optical remote sensing is familiar because it resembles photography: sunlight illuminates the Earth and the sensor records reflected energy. Radar and LiDAR work differently. They are active systems because the instrument provides its own source of energy. This makes them valuable when the required information is not only colour or reflectance, but also structure, distance, roughness, moisture, height or surface movement.

Radar systems transmit microwave pulses and measure the energy that returns from the surface. Synthetic Aperture Radar (SAR) uses the motion of the satellite or aircraft to create an image with a much longer “synthetic” antenna effect. LiDAR, meaning Light Detection and Ranging, transmits laser pulses and measures the travel time of the returned signal to calculate distance. The result is often a dense three-dimensional point cloud.

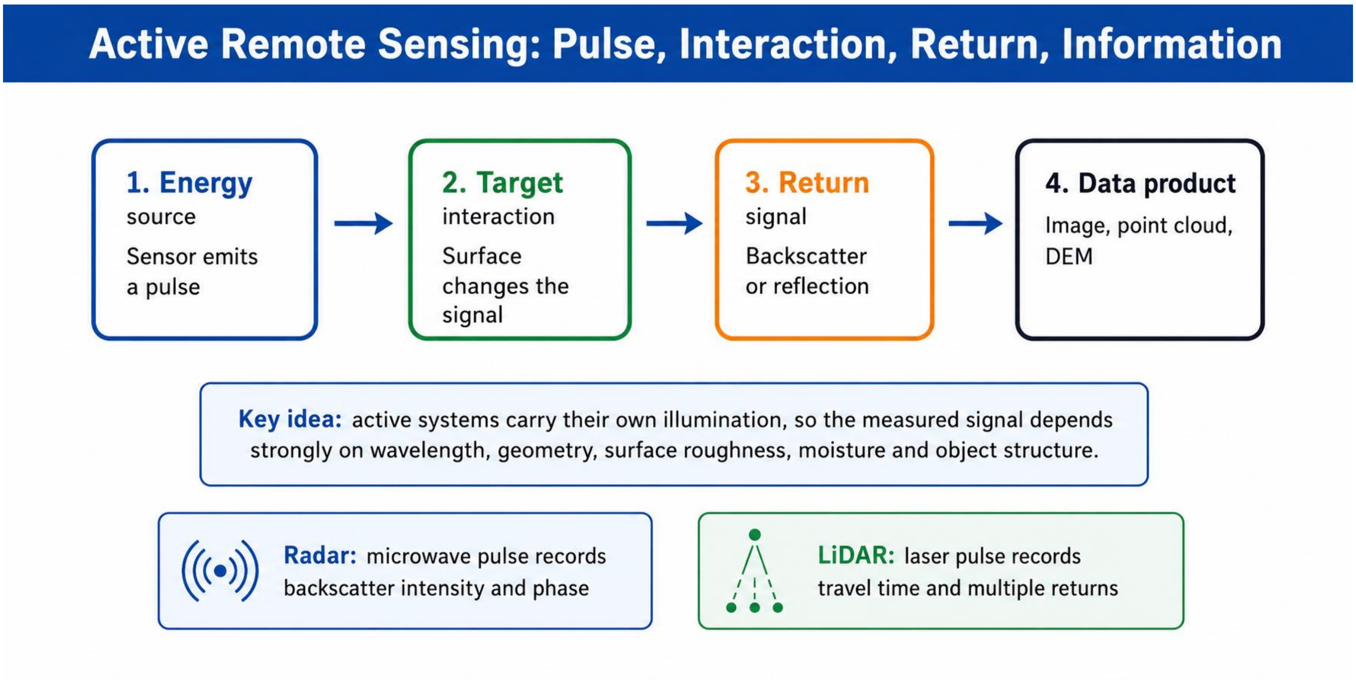

Figure 1. General active remote sensing process: energy emission, interaction, return signal and information product.

Student focus: Do not memorise radar and LiDAR only as “advanced sensors”. Ask what physical property is being measured and how that property supports a real land-management decision.

4. PRINCIPLES OF ACTIVE REMOTE SENSING

An active system has four basic components: a transmitter, a path through the atmosphere, a target surface or object, and a receiver. The measured signal depends on the sensor design and the properties of the target. The same field, canal, wetland, settlement or forest may appear very different depending on wavelength, viewing angle and processing method.

- Passive systems mainly record naturally available energy, while active systems control their own illumination.
- The return signal is not only a visual tone; it is a measurement affected by physics and geometry.
- For practical GIS work, active data should be interpreted together with maps, field notes and local land-use knowledge.

5. RADAR REMOTE SENSING AND SAR

Radar stands for Radio Detection and Ranging. In Earth observation, radar instruments send microwave pulses toward the surface and record the returned signal. The radar image is not a normal photograph. Bright and dark tones are controlled by backscatter: the amount of microwave energy returned to the sensor. Backscatter is influenced by surface roughness, soil or vegetation moisture, object geometry, polarization and wavelength.

SAR is one of the most important radar imaging techniques. The platform moves along its flight or orbital path while recording echoes from the surface. Processing these echoes creates a high-resolution image that behaves as if it had been collected by a much larger antenna. This is why SAR satellites can provide useful images from space even though the physical antenna is limited in size.

Radar factor	Meaning	Why it matters for land studies
Wavelength	Length of the microwave signal	Controls interaction with soil, vegetation, ice and roughness.
Polarization	Orientation of transmitted and received waves	Helps distinguish surface, volume and double-bounce scattering.
Incidence angle	Angle between radar beam and surface normal	Changes brightness, shadow, layover and terrain distortion.
Phase	Position of wave cycle when returned	Used in interferometry to estimate elevation or displacement.

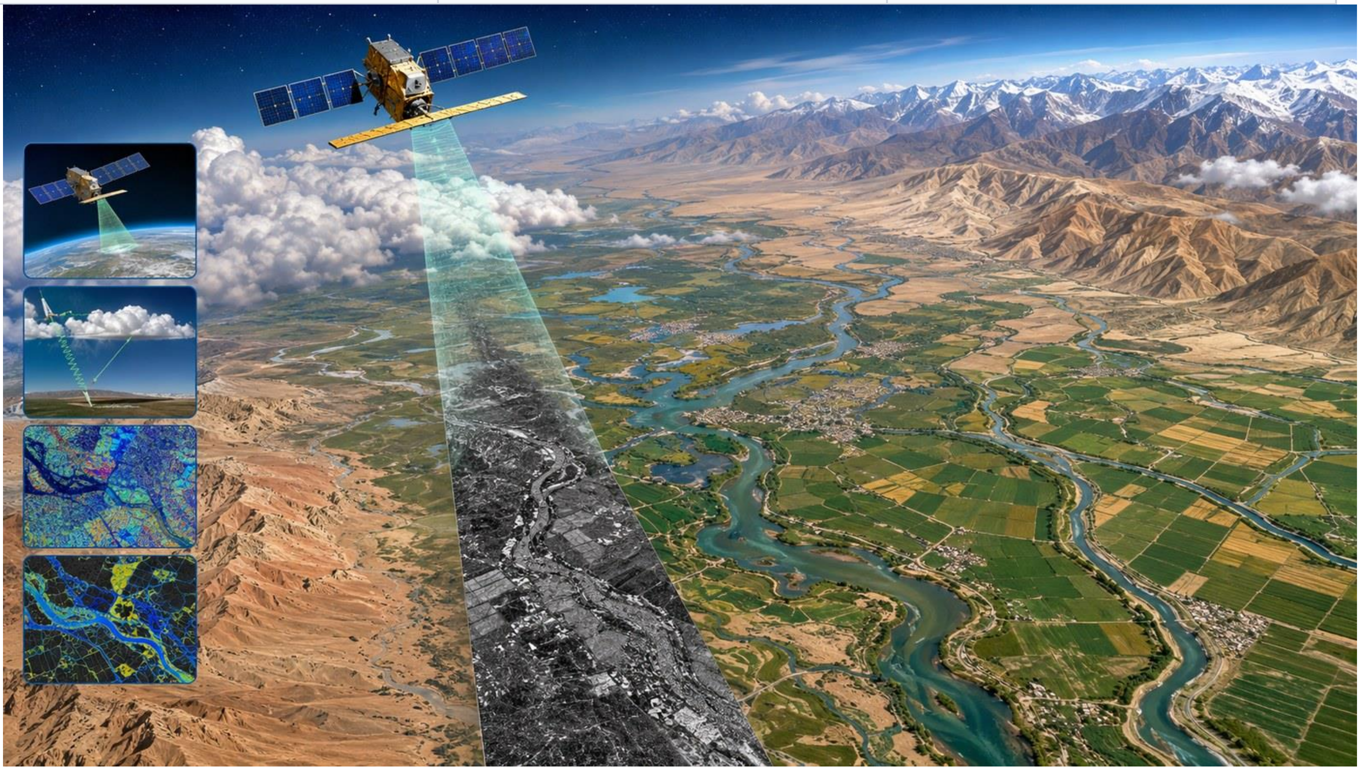

Figure 2. Conceptual SAR observation of land and water surfaces. Radar images require physical interpretation, not only visual interpretation.

A major practical advantage of radar is that microwave energy can support observation in conditions where optical images are reduced by cloud cover or night-time darkness. This makes radar important for emergency mapping, flood monitoring and time-series analysis.

6. RADAR IMAGE INTERPRETATION

Radar interpretation begins with the question: why did this surface return more or less energy to the sensor? Smooth open water often appears dark because most energy is reflected away from the sensor. Rough agricultural fields, built-up areas and vertical structures may appear brighter. Vegetation can produce volume scattering because microwave energy interacts with stems, branches and leaves. Buildings and flooded vegetation can produce double-bounce effects, where energy reflects between a vertical object and a horizontal surface.

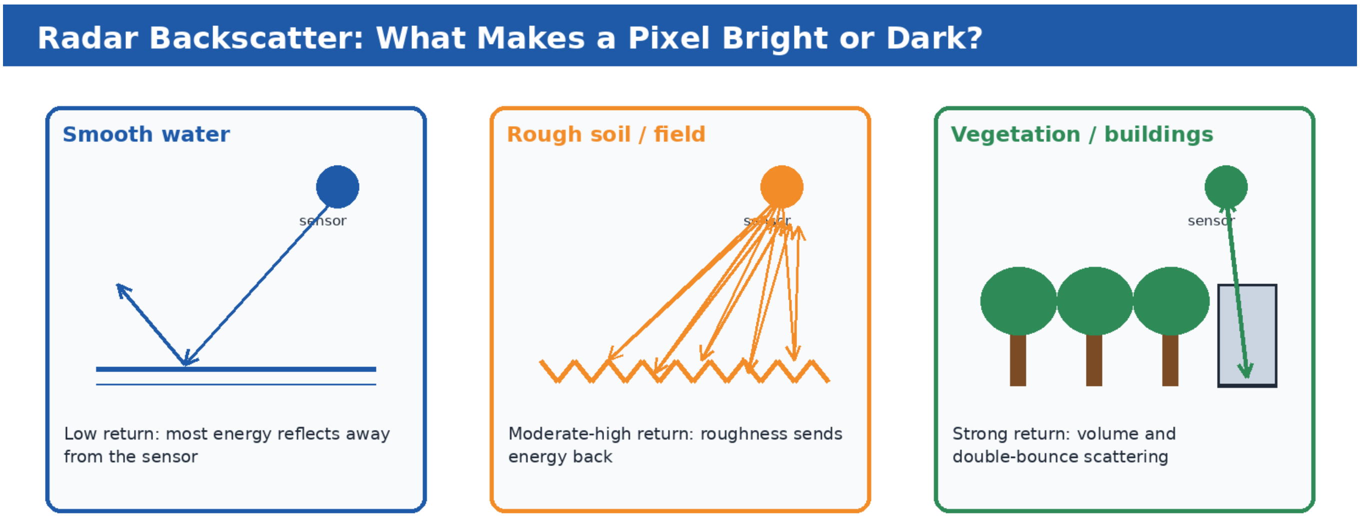

Figure 3. Typical radar backscatter behaviour from smooth water, rough fields and vegetation or urban structures.

Common radar products

- Backscatter intensity images for land cover, flood extent, surface roughness and crop monitoring.
- Multi-temporal SAR stacks for change detection, crop calendars and wetland dynamics.
- Polarimetric products for separating scattering mechanisms in vegetation, soil and urban areas.
- Interferometric SAR (InSAR) products for elevation modelling and surface displacement monitoring.

Important caution: Radar images contain speckle, geometric distortions and angle effects. A bright pixel is not automatically “better” and a dark pixel is not automatically “empty”. Interpretation must be linked to physics, field knowledge and GIS context.

A good interpretation normally checks three things: whether the observed pattern is physically possible, whether the same pattern appears in other dates or bands, and whether local field knowledge supports the conclusion. This habit reduces false mapping results.

7. PRINCIPLES OF LASER AND LiDAR SYSTEMS

LiDAR systems use laser pulses to measure distances. The sensor records the time between pulse emission and return. Since light travels at a known speed, this travel time is converted into range. When range is combined with GNSS positioning and inertial measurements, each return can be located in three-dimensional space. The output is a point cloud: millions of points with x, y and z coordinates, often with intensity and return information.

LiDAR can record multiple returns from a single pulse. In a forest, the first return may come from the canopy top, intermediate returns from branches or understory, and the last return from the ground. This is why LiDAR is useful for both terrain and vegetation analysis. However, laser systems are affected by atmosphere, flight planning, scan angle, pulse density and surface reflectance.

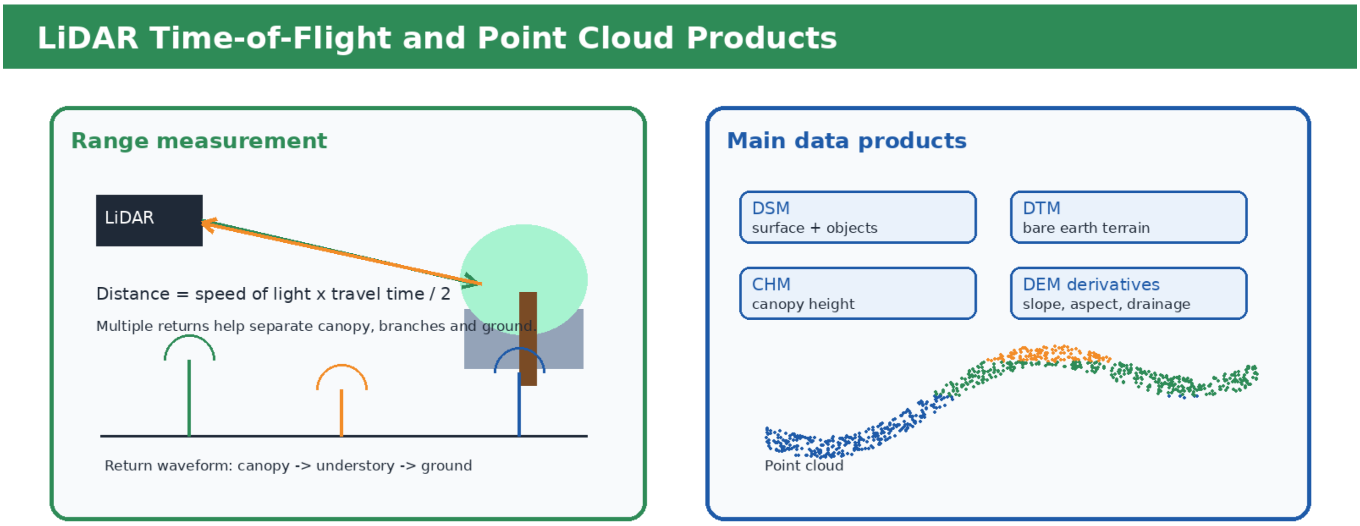

Figure 4. LiDAR time-of-flight measurement and common 3D data products.

Simple formula: Range is calculated from the speed of light and the measured travel time: distance = c x time / 2. The division by 2 is used because the pulse travels to the target and back.

LiDAR system components

- Laser scanner sends pulses and records returns.
- GNSS gives the sensor position during flight or scanning.
- INS records orientation, pitch, roll and yaw.
- Processing software converts returns into classified 3D points and elevation models.

8. LiDAR DATA PRODUCTS AND TERRAIN MODELS

Raw LiDAR data are usually processed into classified point clouds and elevation models. Classification separates ground points from vegetation, buildings, water and other objects. From these classes, analysts derive Digital Surface Models (DSM), Digital Terrain Models (DTM), Digital Elevation Models (DEM), canopy height models and engineering products. For land management, the most important point is that LiDAR can reveal terrain detail that is difficult to extract from ordinary imagery.

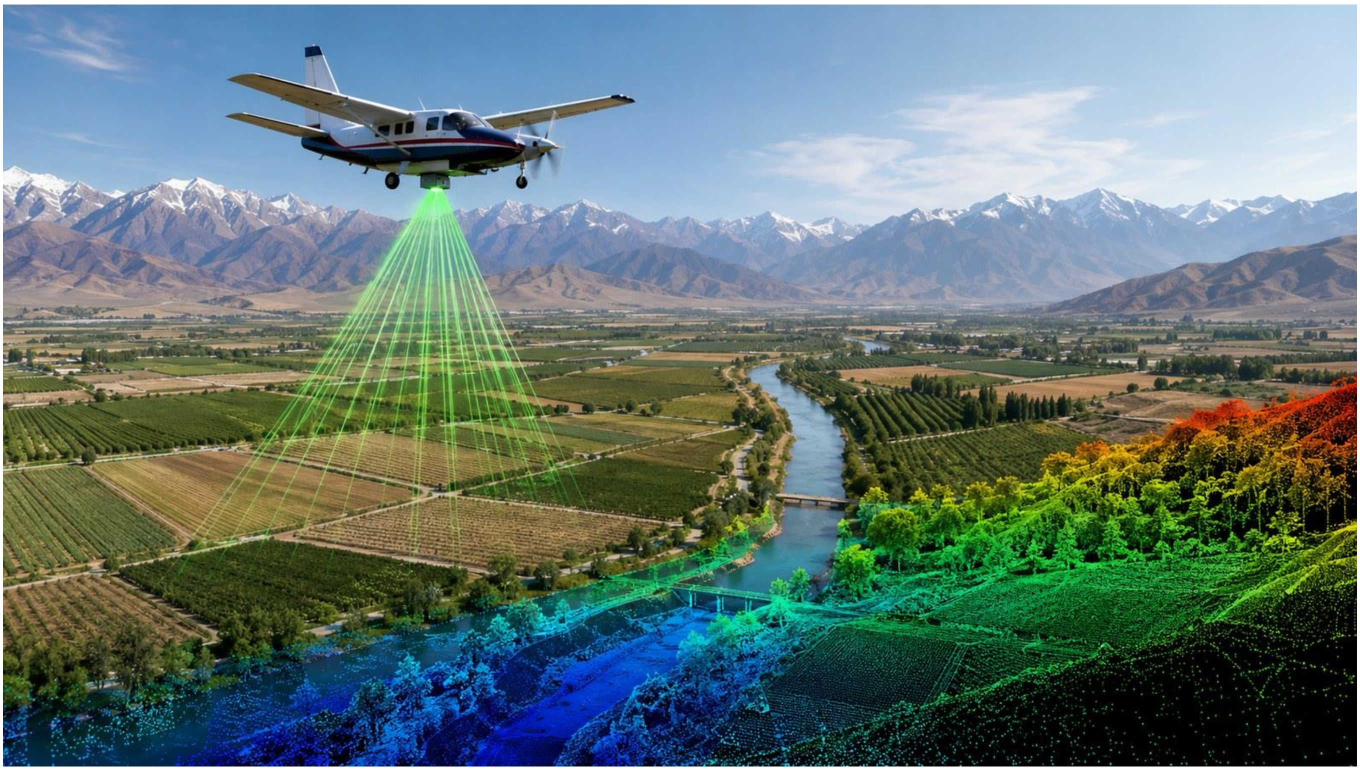

Figure 5. Conceptual LiDAR mapping of terrain and vegetation. Point clouds can be transformed into elevation models and derived maps.

Product	Main content	Typical use
Point cloud	Individual 3D laser returns	Detailed inspection of terrain, trees, buildings and canals.
DSM	Ground plus surface objects	Urban form, canopy surface, object heights.
DTM / bare-earth DEM	Ground surface after filtering objects	Slope, aspect, drainage, erosion and flood modelling.
Canopy Height Model	Vegetation height above ground	Forest structure, windbreaks, biomass indicators.

In irrigated agricultural regions, LiDAR-derived terrain models can support canal design, drainage assessment, land levelling, flood-path modelling and identification of micro-relief that influences water distribution.

9. RADAR AND LiDAR COMPARISON

Radar and LiDAR should not be treated as competing technologies only. They answer different questions. Radar is strong when repeated observation is needed across large areas and difficult weather conditions. LiDAR is strong when very detailed three-dimensional structure is required. In many land and water studies, the best result comes from combining both.

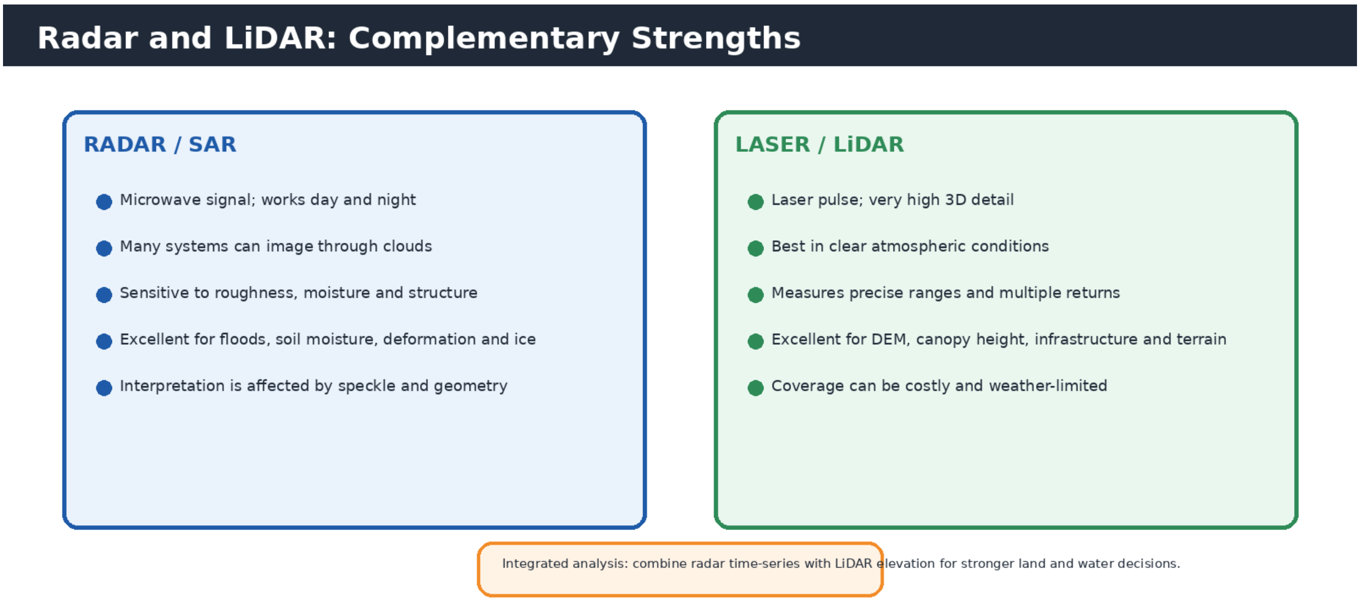

Figure 6. Radar and LiDAR are complementary tools for land and water analysis.

Criterion	Radar / SAR	Laser / LiDAR
Energy	Microwave pulses	Laser/light pulses
Best information	Roughness, moisture, change, deformation	Elevation, height, 3D structure
Weather sensitivity	Can work under many cloudy conditions	Requires clearer atmospheric and flight conditions
Data product	Radar image, coherence, phase, time-series	Point cloud, DEM/DTM/DSM, profiles
Main limitation	Speckle, geometric distortions, specialized processing	Cost, coverage, occlusion, large files

Decision rule: Use radar when timing, weather independence and surface change are critical. Use LiDAR when precise 3D elevation and object structure are critical. Use both when terrain, water and land cover interact.

10. APPLICATIONS IN LAND STUDIES

Radar and LiDAR contribute to land management by providing information that is difficult to obtain from visual inspection alone. Radar time-series help detect land-cover changes, flooded fields, wet soils, crop development patterns, ploughing, roughness and some deformation processes. LiDAR helps quantify terrain, slope, gully forms, field levelling, drainage paths, embankments and infrastructure height. Together, they can support land evaluation, risk mapping and monitoring.

Land-management theme	Radar and LiDAR contribution
Agricultural land	Radar: soil moisture and crop structure; LiDAR: field levelling and canal micro-relief.
Pastures and degradation	Radar: surface roughness and seasonal changes; LiDAR: erosion forms, slope and runoff pathways.
Urban and peri-urban areas	Radar: settlement expansion and deformation; LiDAR: building height, road corridors and drainage detail.
Mountain and foothill terrain	Radar: landslide monitoring and surface movement; LiDAR: detailed DEM, slope, aspect and flow accumulation.

Central Asia and Uzbekistan relevance

In Central Asia, land management is closely linked with irrigation, water scarcity, salinity, mountain runoff, flood risk and desertification pressure. Radar can provide repeated observation of large areas, including periods when optical images are limited. LiDAR can provide the detailed elevation information needed for canals, drainage, erosion assessment and local engineering design.

Example task for students: Choose one irrigated district. Identify which problem requires radar time-series and which problem requires LiDAR elevation data. Explain why one sensor alone may not be sufficient.

For example, radar may show that a field stayed wet after irrigation, while LiDAR may show that the same field has small topographic depressions. Together, these observations can support more precise drainage or land-levelling recommendations.

11. APPLICATIONS IN WATER STUDIES

Water studies benefit strongly from radar and LiDAR because water is both dynamic and topographically controlled. Radar is widely used for flood mapping because smooth open water often gives a low return and can be separated from surrounding rougher surfaces. It is also useful for wetlands, reservoir margins, river ice in some regions and soil moisture studies. LiDAR supports flood modelling because precise elevation is essential for understanding where water can flow, pond or damage infrastructure.

Workflow step	Purpose
1. Define decision problem	Flood extent, canal maintenance, erosion risk, wetland change or land subsidence.
2. Select data	SAR time-series for change; LiDAR point cloud or DEM for terrain; optical imagery for land-cover context.
3. Pre-process	Radiometric correction, terrain correction, speckle filtering, point-cloud classification and DEM generation.
4. Extract indicators	Water mask, backscatter change, slope, flow accumulation, height, terrain roughness or canopy height.
5. Validate and communicate	Use field data, GPS points, local maps and clear visual outputs for decision makers.

Interpretation cautions

- A radar water mask may confuse smooth roads, shadows or very dry flat surfaces with water unless GIS context is used.
- Vegetation can hide water in optical images, while radar may show double-bounce from flooded vegetation.
- LiDAR DEM quality depends on point density, ground classification and vertical accuracy.
- Neither radar nor LiDAR replaces field validation; they help target and improve field work.

Practical message: For water and land studies, the strongest analysis links sensor physics, terrain context, land-use knowledge and field verification.

In a teaching laboratory, students can start with a simple comparison: map open water from SAR, derive slope and flow accumulation from a LiDAR or DEM layer, then explain where the two products agree and where additional field checking is needed.

12. CONCLUSIONS

Radar and LiDAR are essential active remote sensing tools for modern land and water studies. Radar provides large-area, repeated observations and is especially valuable where cloud cover, night-time conditions or surface change make optical data insufficient. LiDAR provides detailed three-dimensional information and is especially valuable when terrain, height, slope and structure are central to the problem.

The most important educational point is that these technologies measure physical interactions, not only “pictures”. Radar brightness depends on microwave scattering processes. LiDAR points depend on laser travel time, return structure and system geometry. Therefore, interpretation requires understanding sensor physics, local land conditions and the purpose of analysis.

Key terms introduced in Week 14

Term	Working meaning
Active remote sensing	A method where the sensor emits its own energy and records the returned signal.
Backscatter	Energy returned from the target surface to the radar sensor.
Synthetic Aperture Radar (SAR)	Radar imaging method that uses platform movement to create high-resolution images.
Speckle	Grainy noise-like pattern common in coherent radar images.
LiDAR	Light Detection and Ranging; a laser-based method for measuring distance and producing 3D point clouds.
Point cloud	A collection of 3D points representing surfaces and objects.
DEM / DTM / DSM	Elevation products representing terrain and/or surface objects.
InSAR	Interferometric SAR method using phase differences to estimate elevation or surface displacement.

Review question: When would you choose radar instead of LiDAR, and when would you combine both? Give one land example and one water example.

Short self-check

- Can you explain why open water is often dark in SAR images?
- Can you name one LiDAR product used for terrain analysis?
- Can you identify one reason why field validation is still necessary?

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Suggested independent study

- Open a Sentinel-1 SAR image and identify smooth water, urban areas and irrigated fields.
- Compare a LiDAR-derived DEM with a coarser DEM and discuss what terrain details are gained.
- Prepare a short map interpretation explaining how radar and LiDAR can support irrigation, drainage or flood-risk decisions in Uzbekistan.

End of lesson: Students are encouraged to review the references and practise with real open data where possible. Understanding radar and LiDAR improves the ability to make stronger GIS-based land and water decisions.

Note: figures in this lesson are conceptual teaching visuals prepared for classroom explanation; they are not field-validated measurement products. For operational work, students should use documented satellite, airborne or UAV datasets and report metadata clearly.