ERASMUS-EDU-2023-CBHE
Project number: 101129032

Duration: 36 months
(01/01/2024 – 31/12/2026)

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LAND MANAGEMENT IN CENTRAL ASIA

14.- Radar and Laser Remote Sensing

Principles of Laser and LiDAR Systems

LM-W14-V95

Principles of Laser and LiDAR Systems

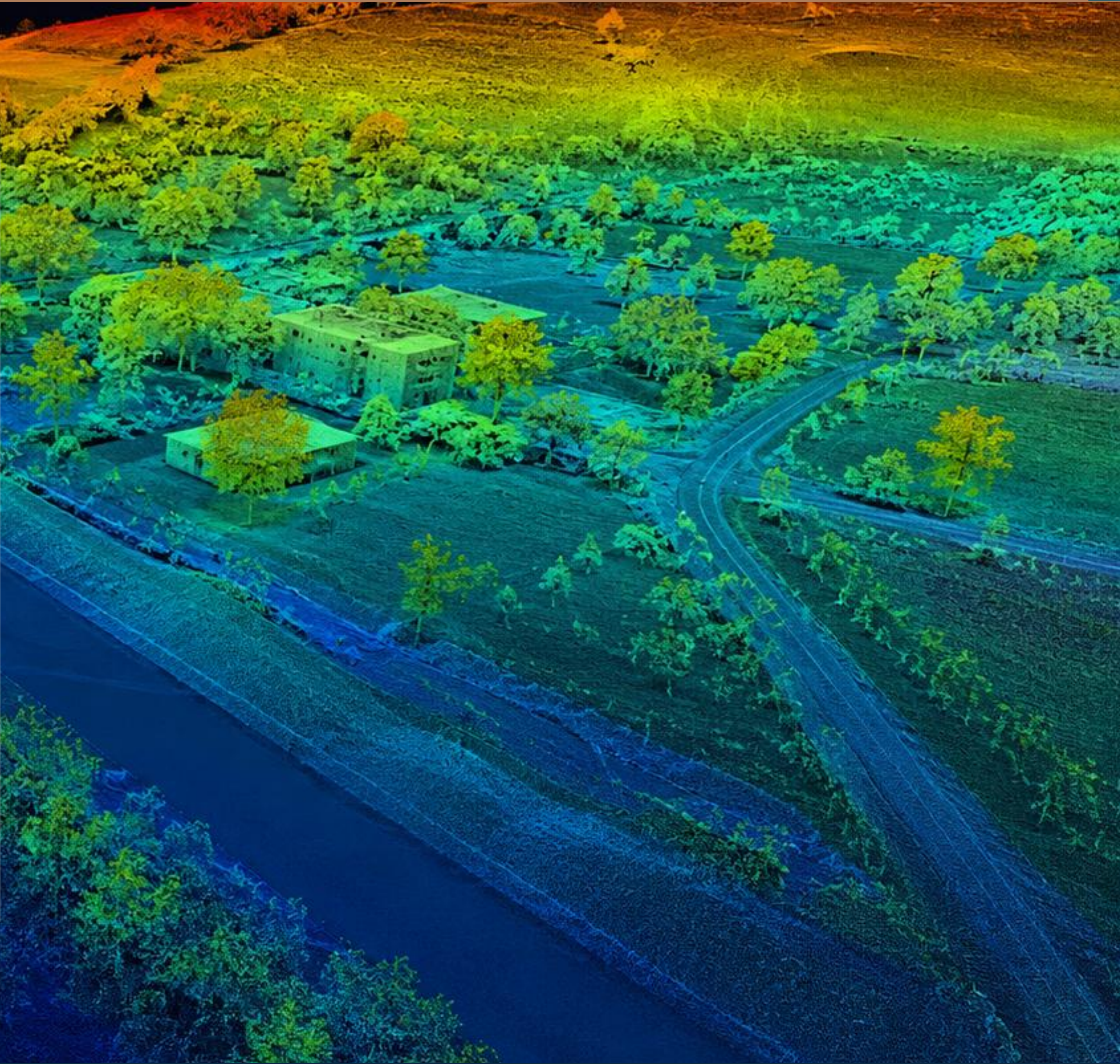
Remote Sensing for Land Management in Central Asia

Micro-credential lesson presentation

Learning objectives

What students should understand after this lesson

- Explain LiDAR as an active remote sensing method using laser pulses.
- Describe how time-of-flight measurements are converted into distance and elevation.
- Identify the main LiDAR system components: laser scanner, GPS/GNSS, IMU and processor.
- Distinguish point clouds, returns, DEM, DSM and canopy height products.
- Evaluate typical land, water, forestry and infrastructure applications.



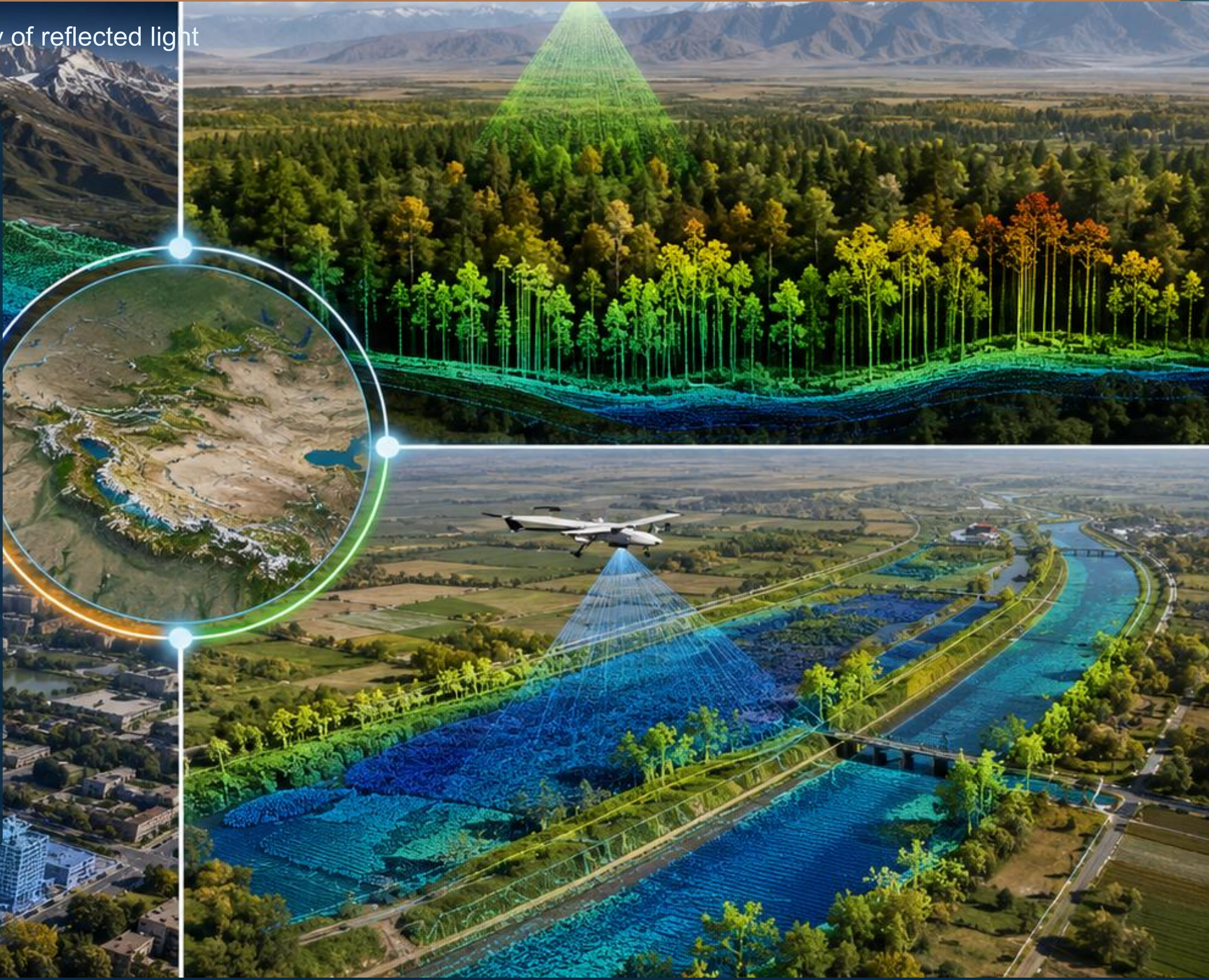
Why Lasers in Remote Sensing?

LiDAR uses its own energy source and measures the geometry of reflected light

Core idea

- A laser pulse is emitted from a sensor.
- The pulse interacts with terrain, vegetation, buildings or water surface.
- Returned energy is recorded with precise timing.
- Each valid return becomes a 3D point.

Active sensing = controlled signal

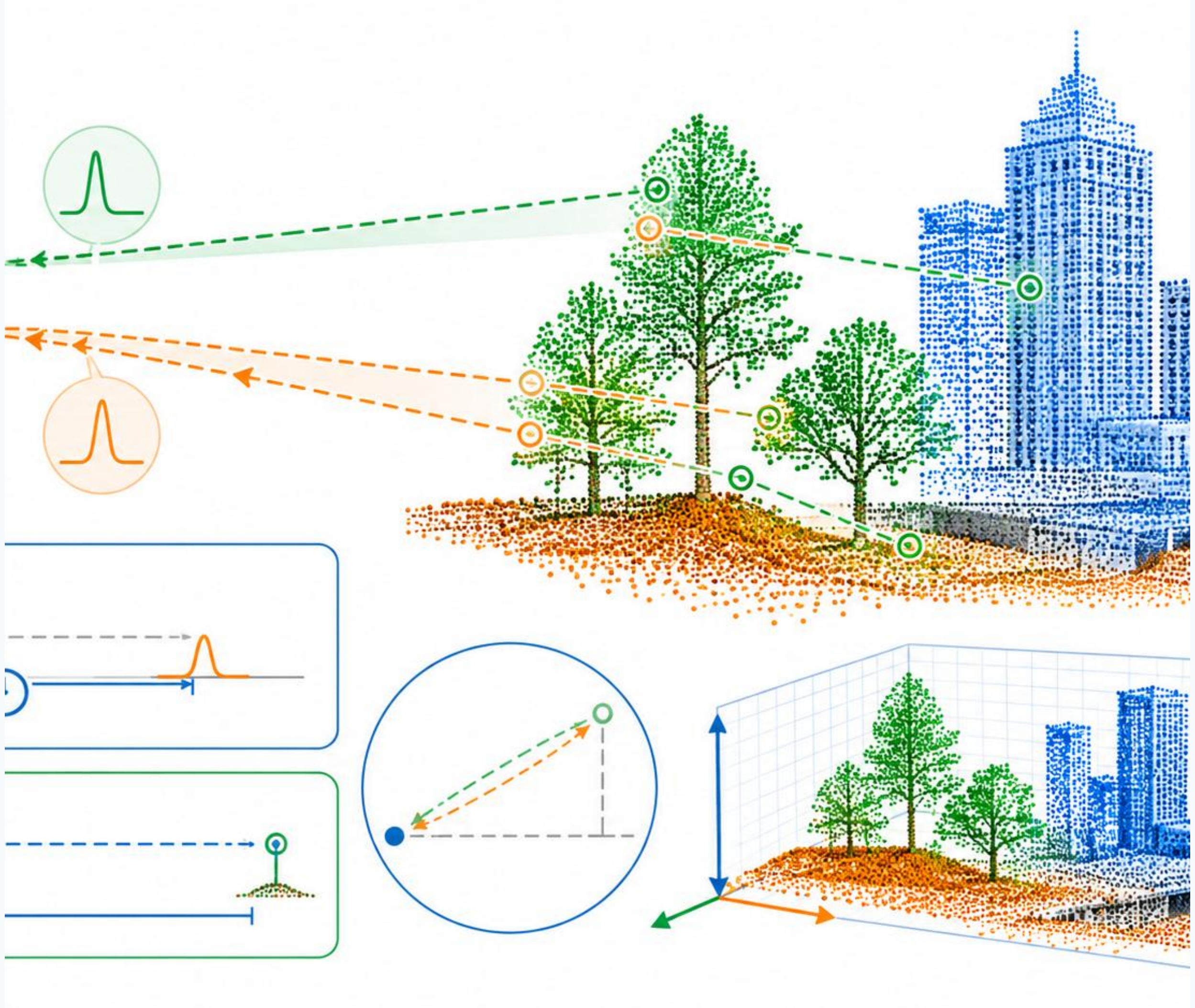


Distance is calculated from pulse travel time

Distance calculation

Range = (speed of light × travel time) / 2

- The pulse travels to the target and back to the sensor.
- The division by 2 accounts for the two-way path.
- Very accurate timing enables very dense elevation measurements.
- Position and orientation data are needed to place every point correctly.



Main Components of a LiDAR System

A LiDAR product is created by combining laser ranging with navigation data

1

Laser scanner

Emits pulses and records returned energy

2

GNSS/GPS

Gives the platform position

3

IMU

Measures roll, pitch and yaw

4

Clock & processor

Synchronizes range, position and orientation

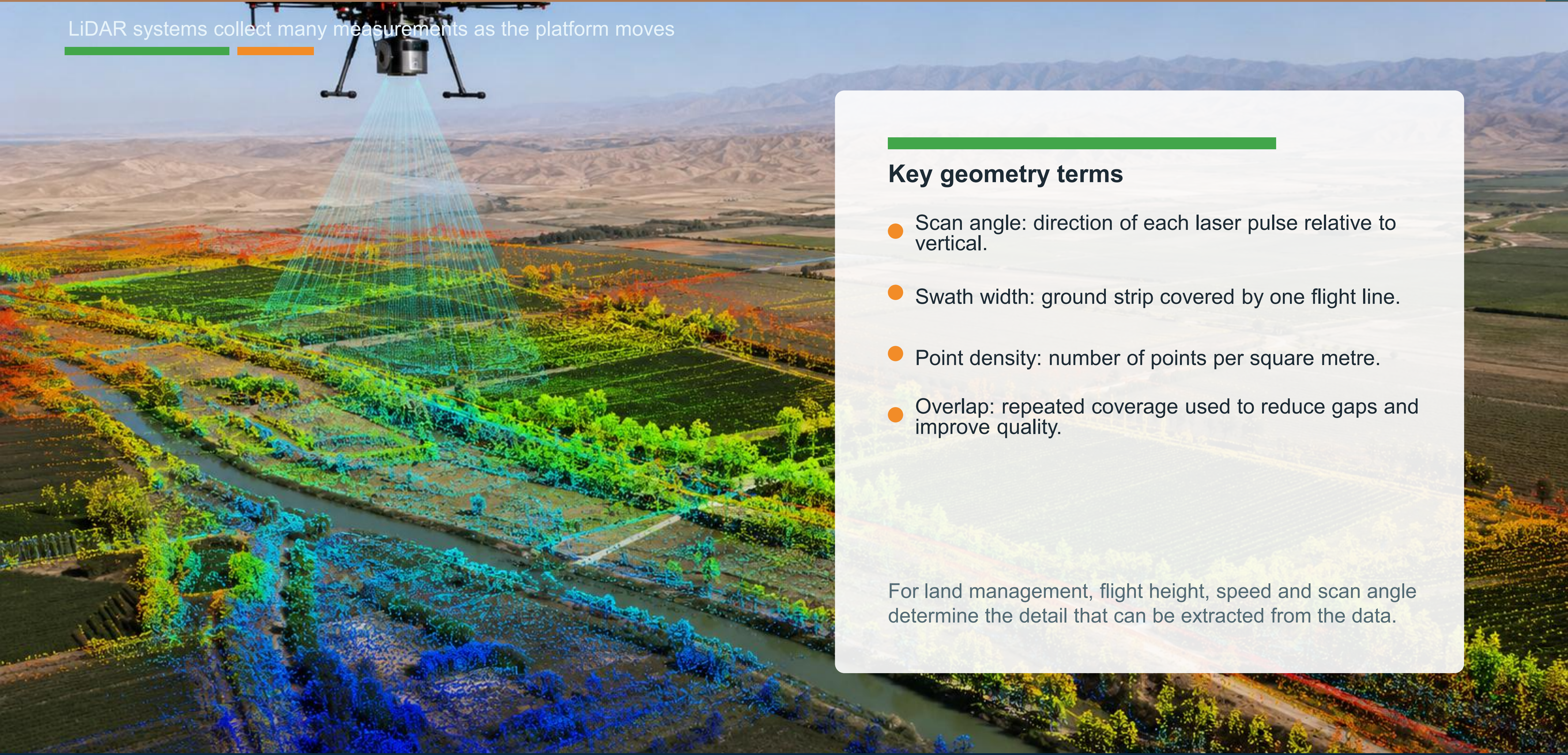
5

Storage & software

Produces point clouds and terrain products

Laser + GNSS + IMU = georeferenced 3D points

Scanning Geometry and Swath



LiDAR systems collect many measurements as the platform moves

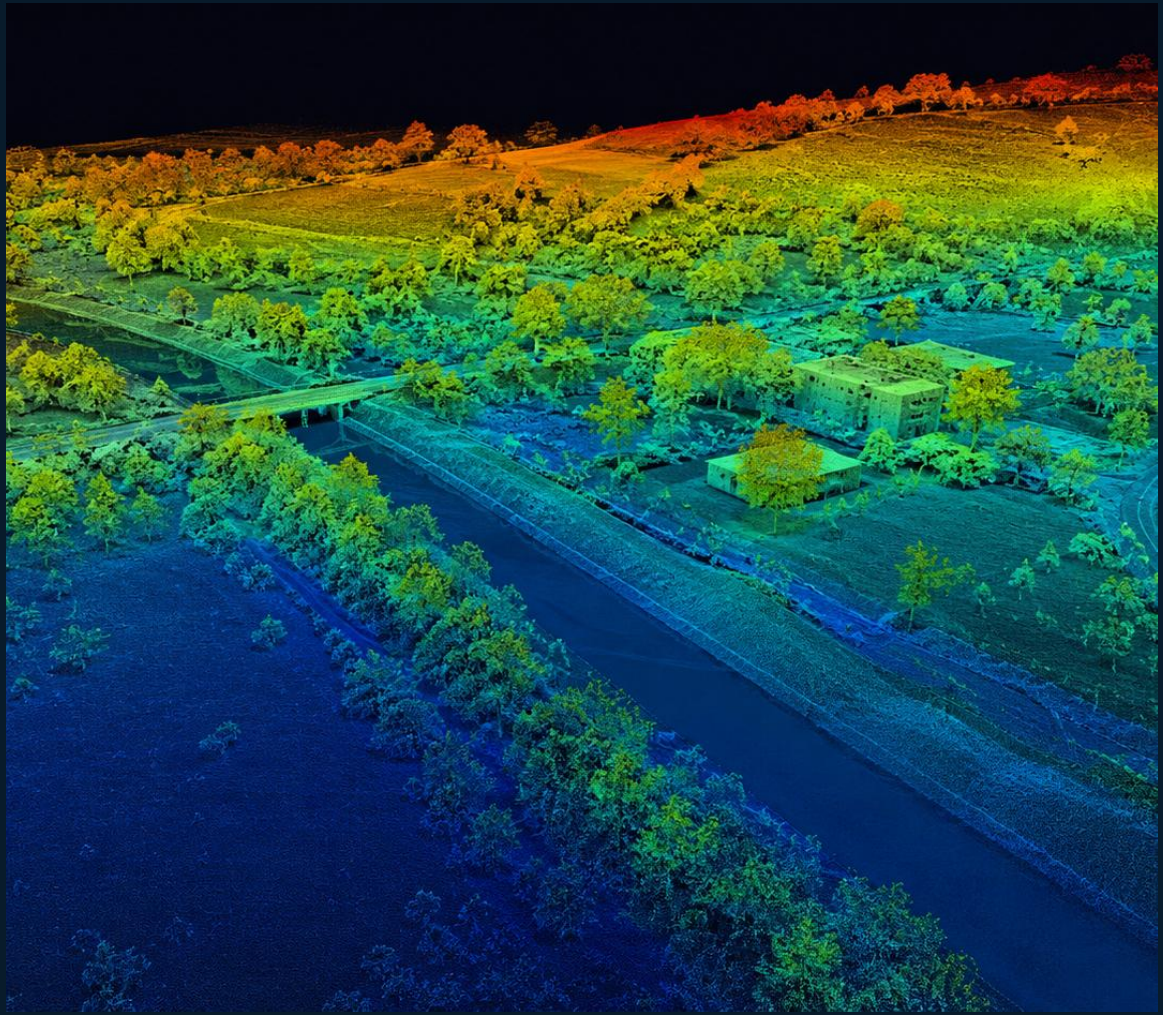
Key geometry terms

- Scan angle: direction of each laser pulse relative to vertical.
- Swath width: ground strip covered by one flight line.
- Point density: number of points per square metre.
- Overlap: repeated coverage used to reduce gaps and improve quality.

For land management, flight height, speed and scan angle determine the detail that can be extracted from the data.

Point Cloud: The Basic LiDAR Data Form

Millions of XYZ points describe the 3D surface and objects



What each point may contain

- X, Y, Z coordinates
- Intensity or return strength
- Return number and number of returns
- Classification: ground, vegetation, building, water, noise
- Time stamp and flight-line information

From points to models

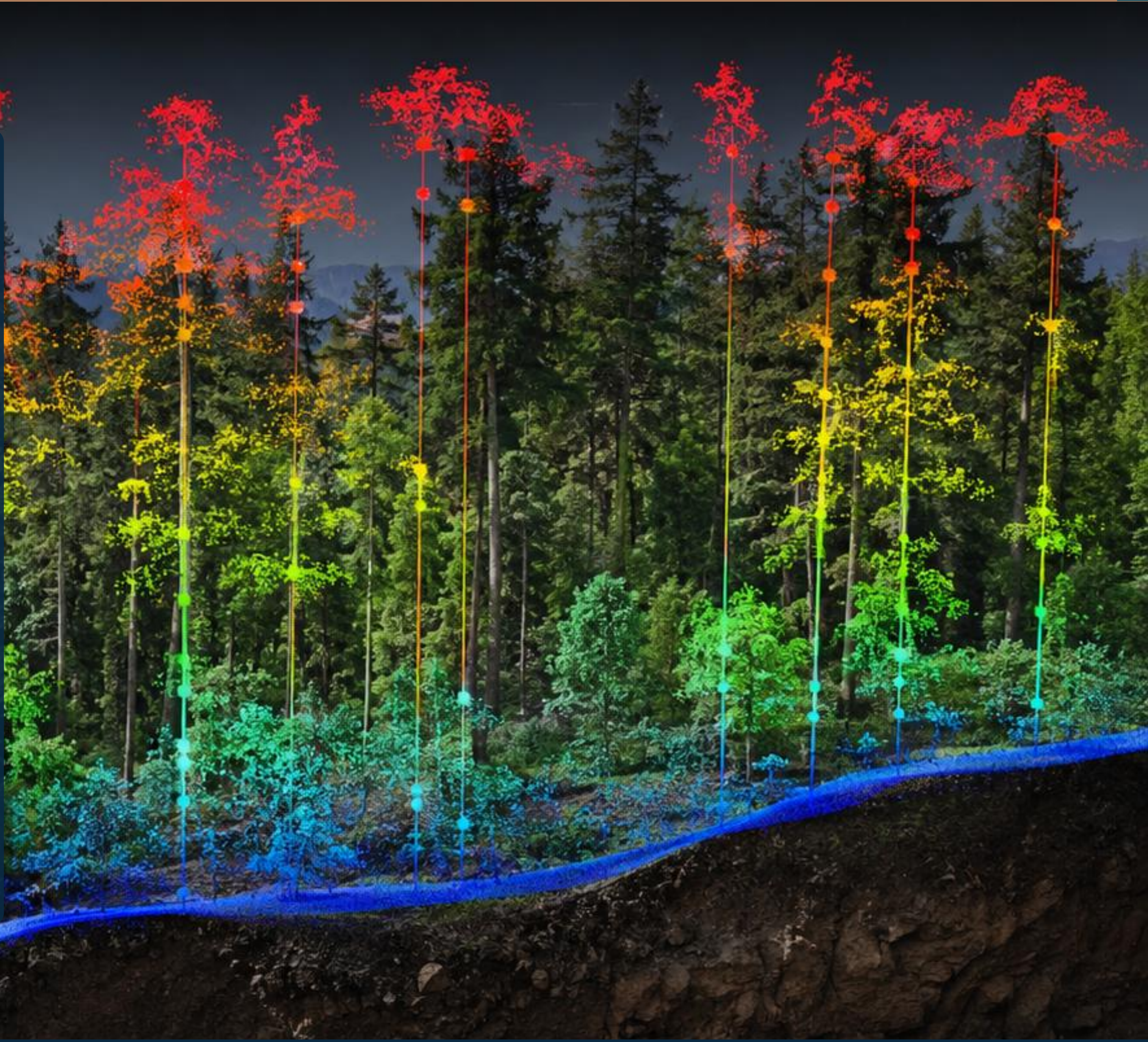
Returns and Waveforms

One pulse can interact with tree tops, branches, understory and ground

Multiple returns help separate vertical structure

- First return often represents the highest intercepted surface.
- Intermediate returns can come from branches and understory.
- Last return may represent the ground or a lower object.
- Full-waveform LiDAR records the complete energy profile over time.

This is why LiDAR is powerful for forestry, biomass studies and canopy-height modelling.



LiDAR Platforms

The same principle can be used from the ground, air or space

Terrestrial

Tripod or mobile scanners for buildings, roads and detailed survey.

cm-level detail

UAV / drone

Flexible low-altitude mapping for farms, canals and small areas.

site scale

Airborne

Efficient regional mapping for DEMs, floodplains and urban planning.

regional scale

Spaceborne

Large-scale vertical structure observations, especially forests and ice.

continental sampling

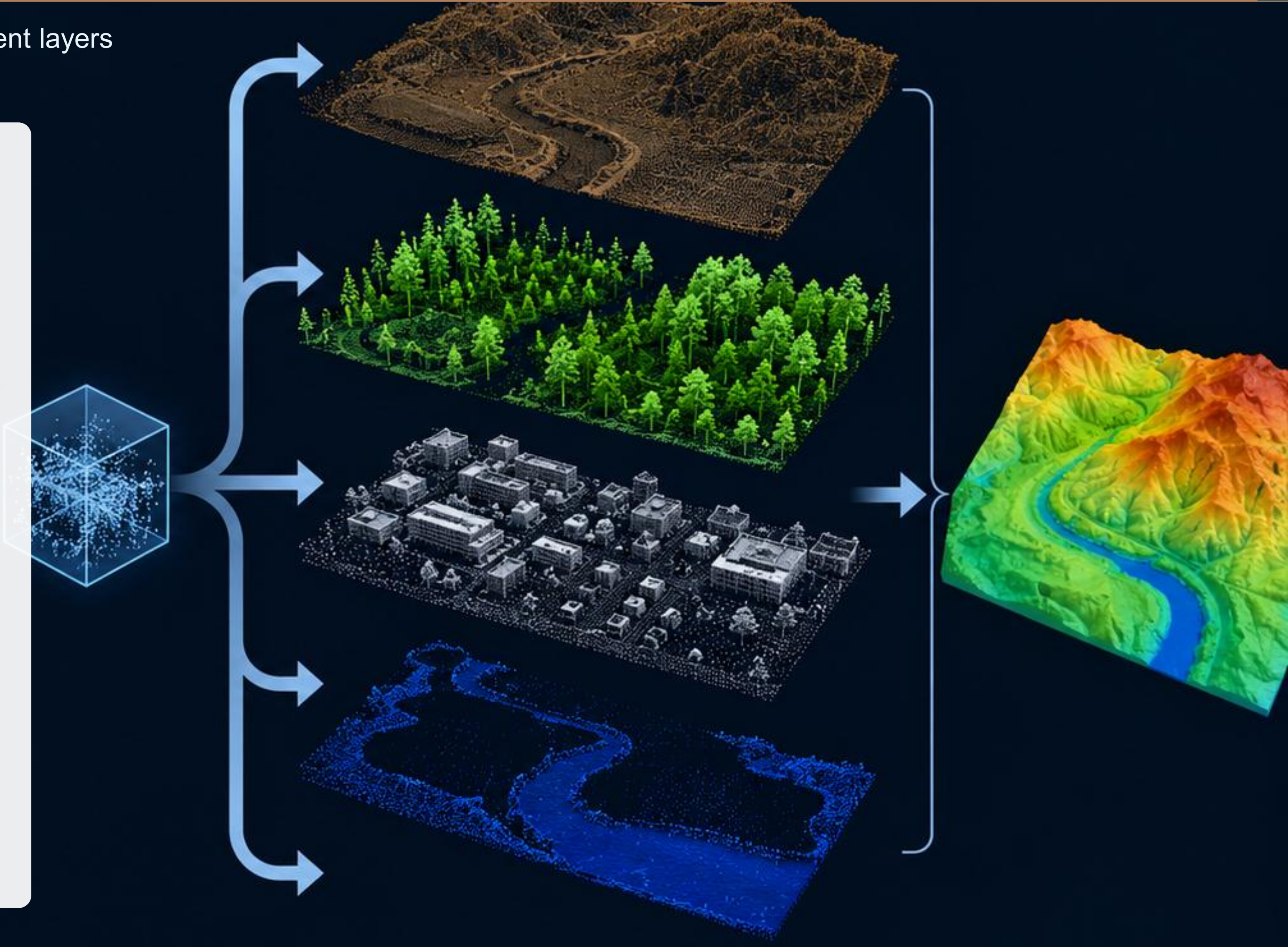
From Raw Points to Usable Products

LiDAR processing converts dense points into land-management layers

Typical workflow

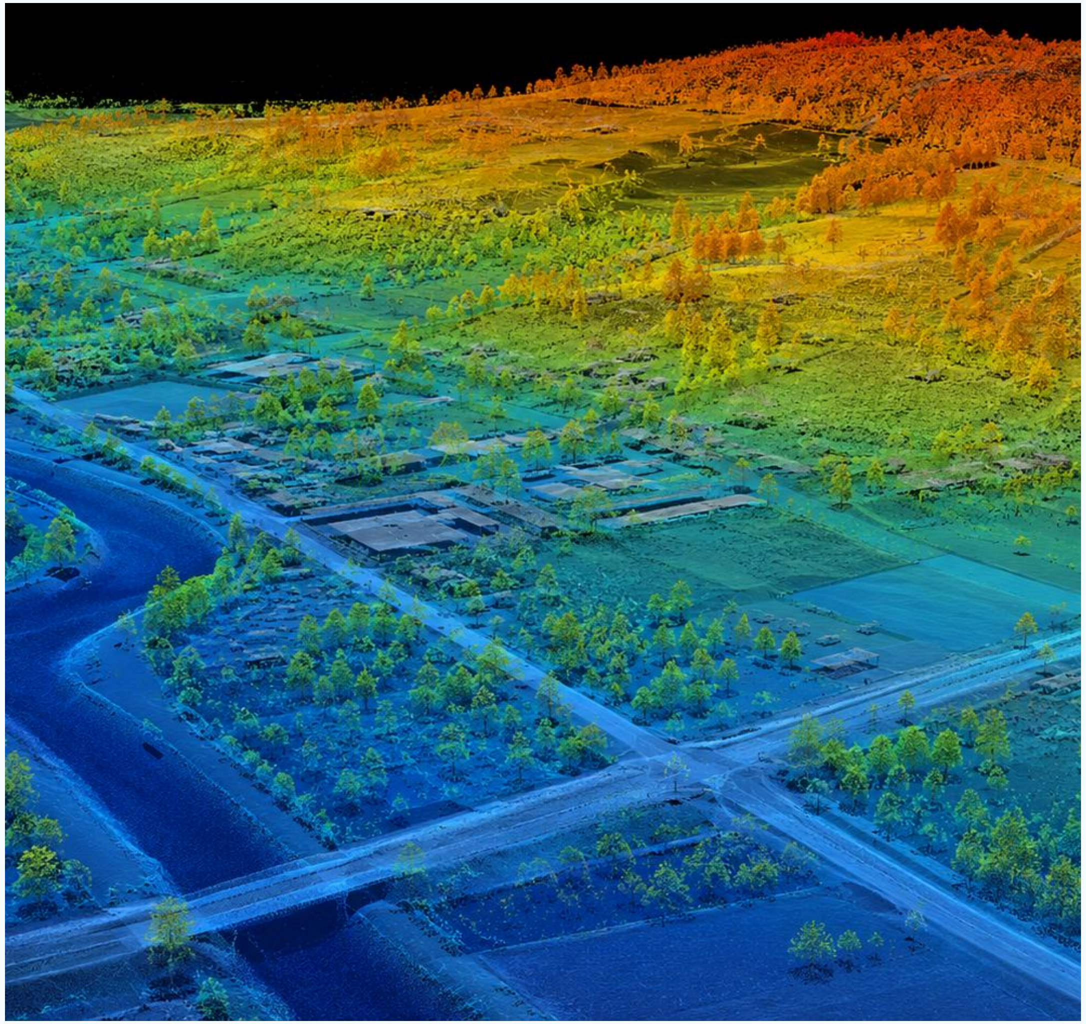
1. Data acquisition
2. Georeferencing
3. Noise filtering
4. Ground classification
5. DEM / DSM production
6. GIS analysis & map output

Quality control is essential: check point density, vertical accuracy, gaps, classification errors and coordinate system.



DEM, DSM and Canopy Height Models

Different products answer different terrain and vegetation questions



DEM bare-earth terrain after removing trees and buildings

DSM top surface including buildings, vegetation and infrastructure

CHM canopy height: DSM or vegetation surface minus DEM

These products support slope analysis, drainage planning, erosion risk mapping, infrastructure design and land monitoring.

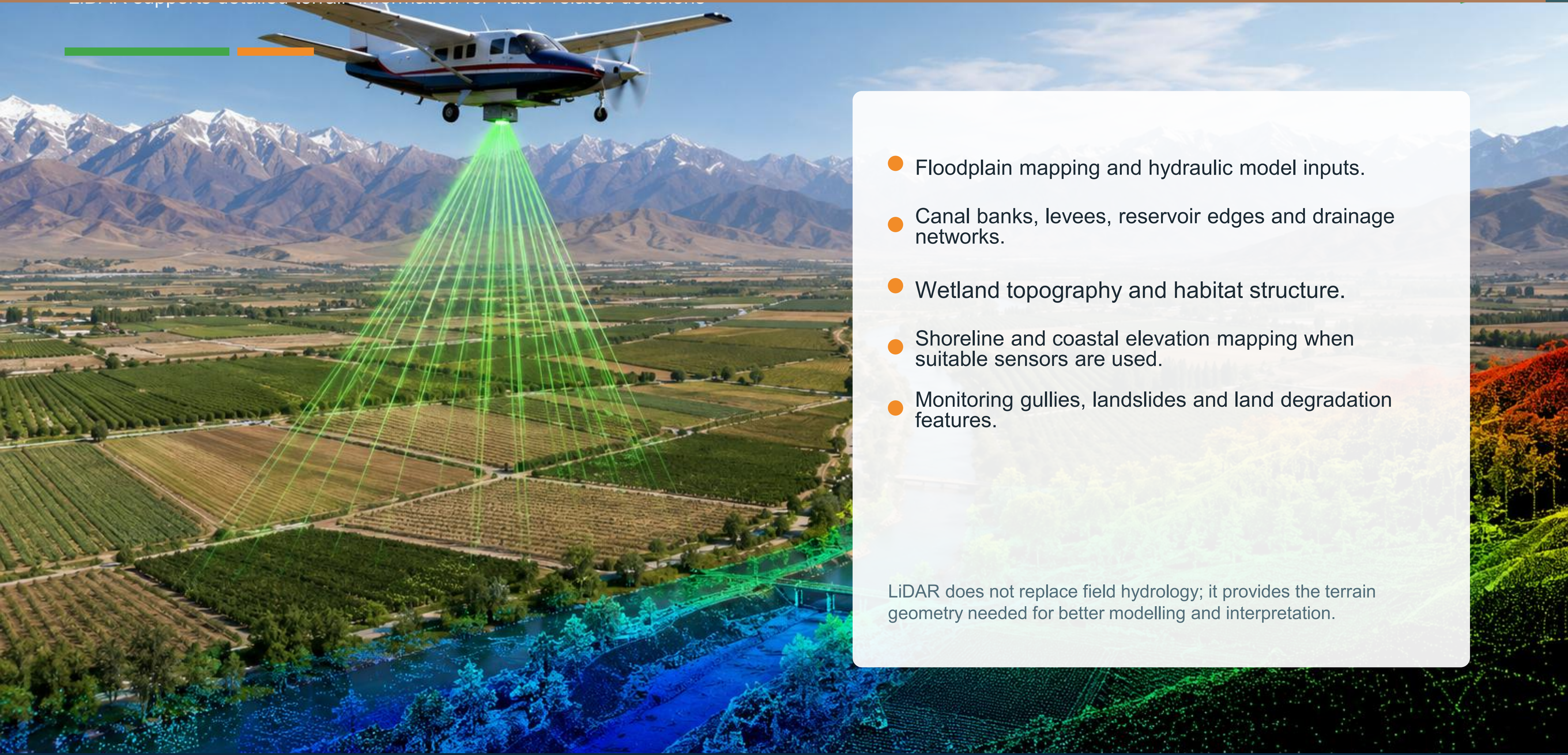
Applications in Land Management

High-resolution elevation data improves spatial decisions in agriculture and cadastre

- Boundary and infrastructure mapping at local scale.
- Slope, aspect and micro-relief analysis for erosion risk.
- Canal, road, embankment and drainage corridor assessment.
- Crop and orchard structure mapping from UAV LiDAR.
- Support for land consolidation, planning and monitoring.

Useful for irrigated landscapes of Central Asia

Water, Flood and Environmental Studies



- Floodplain mapping and hydraulic model inputs.
- Canal banks, levees, reservoir edges and drainage networks.
- Wetland topography and habitat structure.
- Shoreline and coastal elevation mapping when suitable sensors are used.
- Monitoring gullies, landslides and land degradation features.

LiDAR does not replace field hydrology; it provides the terrain geometry needed for better modelling and interpretation.

Strengths and Limitations

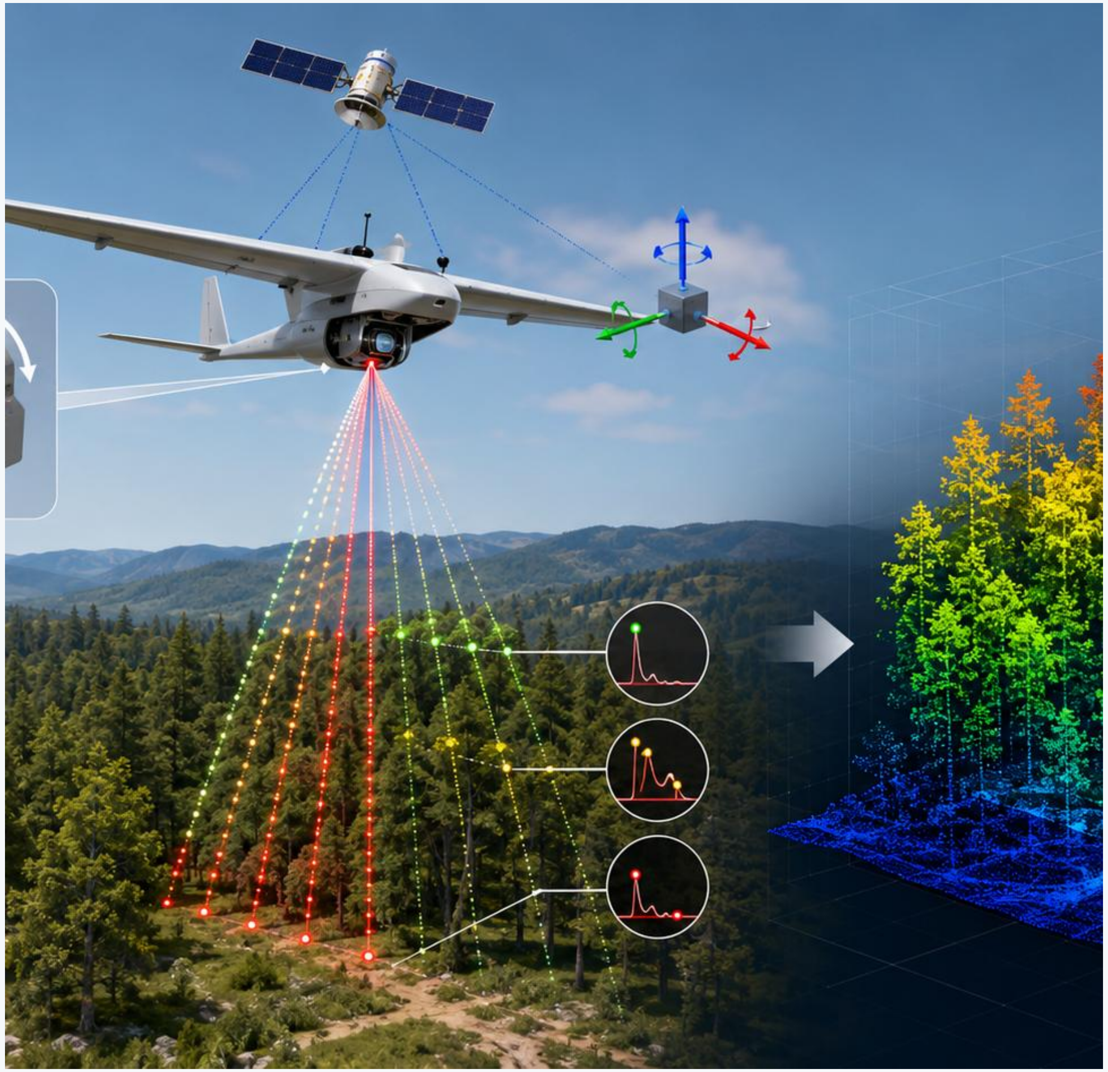
A good analyst understands both the power and the constraints of LiDAR

Strengths

- Very detailed 3D structure
- Accurate elevation products
- Works well for terrain and vegetation height
- Supports GIS-ready mapping products

Limitations

- Requires careful calibration and processing
- Large files and computing needs
- Sensitive to platform navigation quality
- Water and very dark surfaces may be challenging



Key Takeaways and References

Laser and LiDAR systems turn timed light pulses into 3D geospatial information

Key takeaways

- LiDAR is an active remote sensing system based on laser pulses.
- Time-of-flight measurements are combined with GNSS and IMU data.
- Point clouds are processed into DEM, DSM and other GIS products.
- Applications include terrain, forestry, infrastructure, water and land monitoring.

Selected references

USGS. What is LiDAR? Interagency LiDAR Monitoring & Research Applications.

NOAA National Ocean Service. What is lidar? Updated 2024.

NASA Earthdata. Global Ecosystem Dynamics Investigation LiDAR (GEDI).

NEON. The Basics of LiDAR — Light Detection and Ranging. Updated 2026.

Shokirov, Musaev & Akbarov. Masofadan zondlash. Tashkent, 2015.

Reflection question: Which LiDAR product would be most useful for monitoring irrigated agricultural land in your region, and why?

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