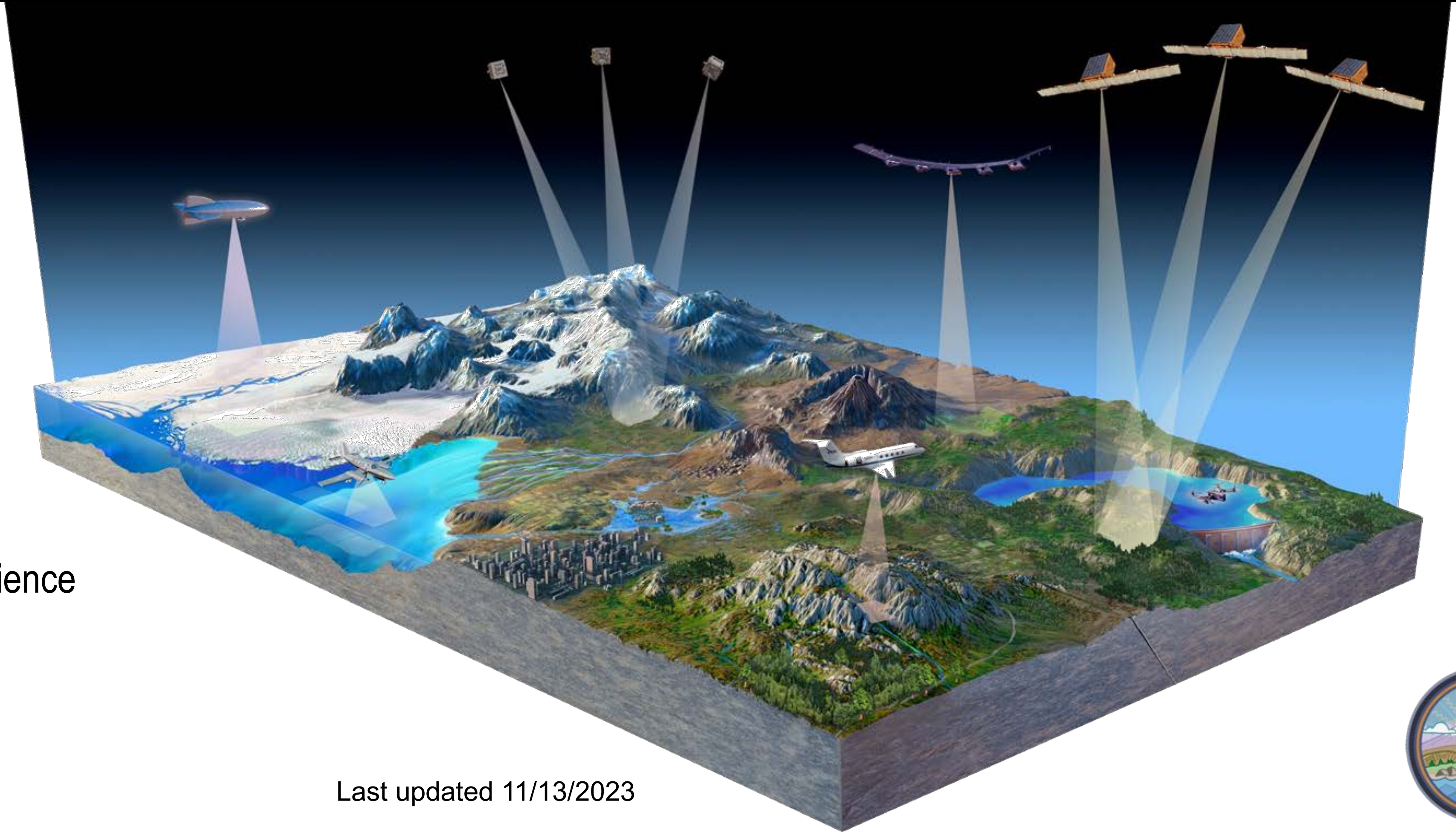
NASA's Surface Topography and Vegetation Study

LIDAR



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Last updated 11/13/2023

LIDAR Current Capability Overview

Current (TRL6 spaceborne)

Spaceborne:

Mission	Coverage	Ground tracks	Wavelength	Technology	Along track sampling	Footprint size	Per-pulse energy	Repeat cycle
ICESat-2	+- 88	6	532 nm	Photon counting	0.7 m	11 m	0.03 mJ/0.12 mJ	91 days
GEDI	+- 51.6	8	1064 nm	Full-waveform	60 m	25 m	10 mJ	N/A
GaoFen-7	+-82.6	2	1064 nm	Full-waveform	2.4 km	20 m	100-180 mJ	N/A

TRL6 Definition: System/Subsystem model or prototype demonstration in a relevant environment

LIDAR Current Capability Overview

Selection of TRL6-Airborne sensors from the STV – 21 report

Vendor	Altitude (e.g.)	Swath width	Sampling (100 m/s)	Wavelength	Footprint
NASA/ATM	1000 m	250 m	1 / 3 m	532 nm	0.6 m
NASA/LVIS	7000 m	2 km	10-20 m	1064 nm	25 m
Teledyne Pegasus	5000 m	1000 m	0.5 m	1064 nm	<1 m
Teledyne Nova	1000 m	350	2 m	532 nm	7 m
Leica ALS 80	5000 m	1000 m	0.2	1064 nm	<1 m
Leica Chiroptera	600 m	200	0.4	532 nm	3 m
Reigl VQ-1560	3700	4-8 km	0.4 m	1064 and 532	<1 m

TRL6 Definition: System/Subsystem model or prototype demonstration in a relevant environment

LIDAR Emerging Capability

TRL6 by 2028 (airborne and spaceborne)

Spaceborne:

CASALS

NUVIEW

Geiger-mode flash LIDAR

Imaging LIDAR based on GEDI heritage

TRL6 Definition: System/Subsystem model or prototype demonstration in a relevant environment

LIDAR Emerging Capability

TRL6 by 2028 (airborne and spaceborne)

Spaceborne:

- **CASALS**
  - **Wavelength-tuning laser and grating optics for beam scanning**
  - **High-efficiency photon-counting detectors**
  - **Freeform optics to allow use of smallsat platform**
  - **ML-based real-time data analysis for on-orbit decision making**
- **NUVIEW**
- **Geiger-mode flash LIDAR**
- **Imaging LIDAR based on GEDI heritage**

TRL6 Definition: System/Subsystem model or prototype demonstration in a relevant environment

LIDAR Emerging Capability

TRL6 by 2028 (airborne and spaceborne)

Spaceborne:

- CASALS
- **NUVIEW**
  - **Commercial small-sat based LIDAR constellation**
  - **Low duty cycle for targeted use of resources**
- Geiger-mode flash LIDAR
- Imaging LIDAR based on GEDI heritage

TRL6 Definition: System/Subsystem model or prototype demonstration in a relevant environment

LIDAR Emerging Capability

TRL6 by 2028 (airborne and spaceborne)

Spaceborne:

- CASALS
- NUVIEW
- **Geiger-mode flash LIDAR**
  - **Photon-counting LIDAR over a 2-d array**
- Imaging LIDAR based on GEDI heritage

TRL6 Definition: System/Subsystem model or prototype demonstration in a relevant environment

LIDAR Emerging Capability

TRL6 by 2028 (airborne and spaceborne)

Spaceborne:

- CASALS
- NUVIEW
- Geiger-mode flash LIDAR
- **Imaging LIDAR based on GEDI heritage**
  - **Efficient 1-micron laser and detectors**
    - **-Improvements over GEDI allow 10x improvement in coverage**
    - **-High dynamic range for vegetation and sea ice**
  - **Solid-state scanning system:**
    - **-Fast, accurate and repeatable beam locations**

TRL6 Definition: System/Subsystem model or prototype demonstration in a relevant environment

LIDAR Mapping needs to Measurements

LIDAR measurement parameters

- **Sampling resolution**
- **Per-sample resolution**
- **Repeat frequency**
- **Per-measurement precision**
- **Canopy penetration**
- **Water penetration**

LIDAR instrument parameters:

- **Geolocation precision**
- **Scanning strategy**
- **Wavelength**
- **Pulse repetition frequency**
- **Waveform detection strategy**
- **Digitization rate**
- **Pulse duration**

Mission parameters

- **Mission duration**
- **Orbit**
- **Number of platforms**
- **Supplementary data sources**

LIDAR Mapping to Measurements (from STV-21 report)

Discipline	Footprint size	Horizontal sampling	Repeat interval	Vertical precision	Signal strength	Wavelength	Notes
Vegetation	< 20 m	< 30 m	90 d	1 m	Canopy penetration		Needs are regional
Hydrology		1 m	1 d	0.1 m	Bathymetry needed	Visible	
Coastal processes	3-5	1-15 m	10-30 d	0.1-0.2 m	10-25 m bathymetry	Visible	
Solid Earth	0.5-10	0.5-10	1 d	0.01 m			Precise rates of vertical change
Sea ice	< 20 m	< 20 m		0.01 m	Important	NIR preferred	Measurements in dark leads are essential
Land ice	10-30 m	10-30 m	5-30 d	0.01 m		NIR preferred	Monthly revisit preferred

LIDAR Needed Technology Advances

To completely satisfy the measurement goals in the original STM, LIDAR needs greater coverage than is feasible with current technology

- **Improved transmitter efficiency**
- **Improved detector efficiency**
- **Improved platform efficiency**
- **Adaptable transmit power for measurements over closed canopy forests**
- **Small-sat / multi-platform deployment**
- **Multi-mode LIDAR systems**
- **Downlink / data compression**

LIDAR has potential as a sampling component of a multi-sensor mission. This requires

- **Modeling of measurement approaches to advance multi-sensor algorithms**
- **Mission design for optimal sensor fusion**
- **Development of models to fill other data in LIDAR coverage gaps**

LIDAR Strengths and Weaknesses

Strengths

- **High precision**
- **Mission-to-mission continuity**
- **Fine spatial resolution**
- **Recovery of vertical profiles of canopy density**
- **Recovery of bathymetric profiles**

Weaknesses

- **Difficulty measuring through thick clouds**
  - **Likelihood of successful measurements increases with wider swaths and multi-platform capabilities**
  - **Longer mission duration improves total coverage**
- **Coverage limited by power requirements and scanning hardware**
  - **Adaptable measurement design to efficiently use limited power**

What can be overcome and what is an insurmountable barrier?

LIDAR Synergies

With other technologies

LIDAR/Imagery

- **-Established techniques for ecosystem measurements**
- **-Established techniques for shallow-water bathymetry**
- **-Typically made with instruments on separate platforms**
  - **Ex: https://daac.ornl.gov/CMS/guides/CMS_Global_Forest_AGC.html**

LIDAR/ Stereo Optical / inSAR DEMs

- **-LIDAR makes (almost) bias-free profile measurements for precise reference elevations**
- **-Optical / inSAR measurements provide detailed DEM coverage**
- **-Can be made with a single platform or separate platforms**
- **-Measurements from a single platform offer potential geometric advantages**
- **-Algorithms need to be developed for stereo fusion over vegetation**

LIDAR / radar measurements over vegetation:

- **-LIDAR provides precise profile measurements of canopy structure**
- **-Radar provides broad-swath measurements**
- **-Measurement geometry likely requires multiple platforms**

https://doi.org/10.1016/j.rse.2020.112234

LIDAR Needed Advancements

Advancements needed to achieve STV

Understanding LIDAR measurements:

How does ground-under-canopy accuracy depend on spot sampling and beam energy?

Under what circumstances do we need airborne instead of satellite measurements?

How do science needs constrain laser parameters? (wavelength, pulse width, sampling)

Multi-sensor intercomparison experiments

What sampling is needed from LIDAR to enable fusion products?

What characteristics are needed from the non-LIDAR data?

Potential model: SNOWEX

LIDAR Needed Experiments

Existing and proposed

NEON: Vegetation studies, Hyperspectral / LIDAR

ABOVE : Vegetation and sea ice, Includes LIDAR / hyperspectral

SNOWEX: Multi-sensor (radar /LIDAR / photogrammetry) over seasonal snow

IceBridge: Multi-sensor (radar / LIDAR/ photogrammetry) over land/sea ice, repeat measurements

ArcSix: LVIS plus cloud LIDAR over sea ice

Bioscape: Multi-sensor data fusion in South Africa

Casals airborne demonstration

Summary

- Spaceborne LIDAR can fulfill a subset of science needs defined in the STV-21 report
- Improved total efficiency (laser/detector/platform) can expand LIDAR's abilities
- There is a lot of potential for fusion with other technologies
- Mature science needs will help define the needed balance between LIDAR measurements and measurements from other sensors

- Studies needed to:
  - Explore dependence of measurement precision, coverage, and accuracy on LIDAR characteristics
  - Explore potential for multi-sensor fusion
  - Map measurements to model needs
  - Explore blended airborne and spaceborne measurements