Working towards spaceborne lidar with wall-to-wall coverage for bare-Earth topography and vegetation change mapping: Small-sats, deployable optics and novel laser sources

University of Edinburgh:	Steven Hancock, Johannes Hansen, Ian Davenport, Euan Mitchell, Iain Woodhouse, Kristina Tamane
Fraunhofer Centre for Applied Photonics:	Jack Thomas, Emma Le Francois, Gerald Bonner, Haochang Chen, Paul McCartney, Ludwig Prade, James Morris
UK Astronomy Technology Centre:	Patrick Smith, Stephen Todd, Heather Bruce, David Lunney, Donald Mcleod
Resilience Constellation Management Ltd.:	Richard Tipper, Andy Shaw, Jess Roberts
Space Flow Ltd.:	Callum Norrie
University of Strathclyde:	Chris Lowe, Ciara McGrath

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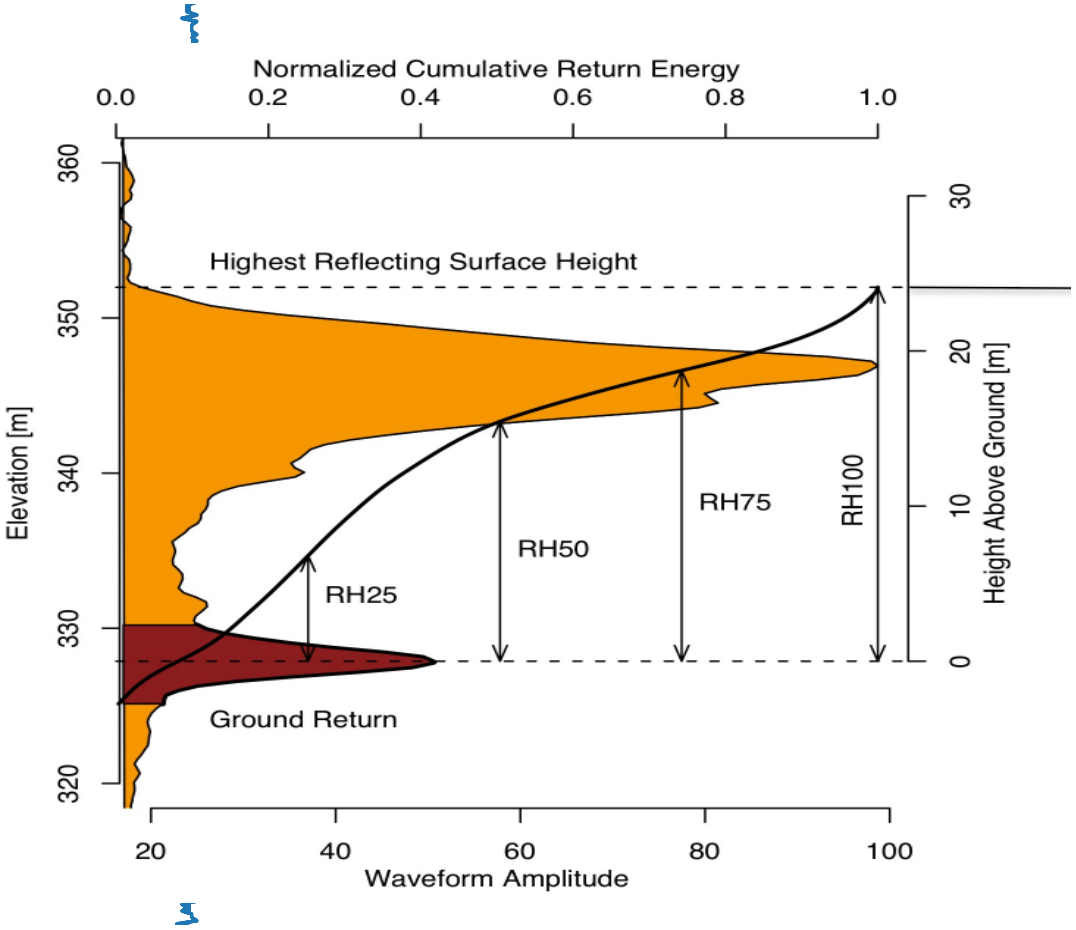
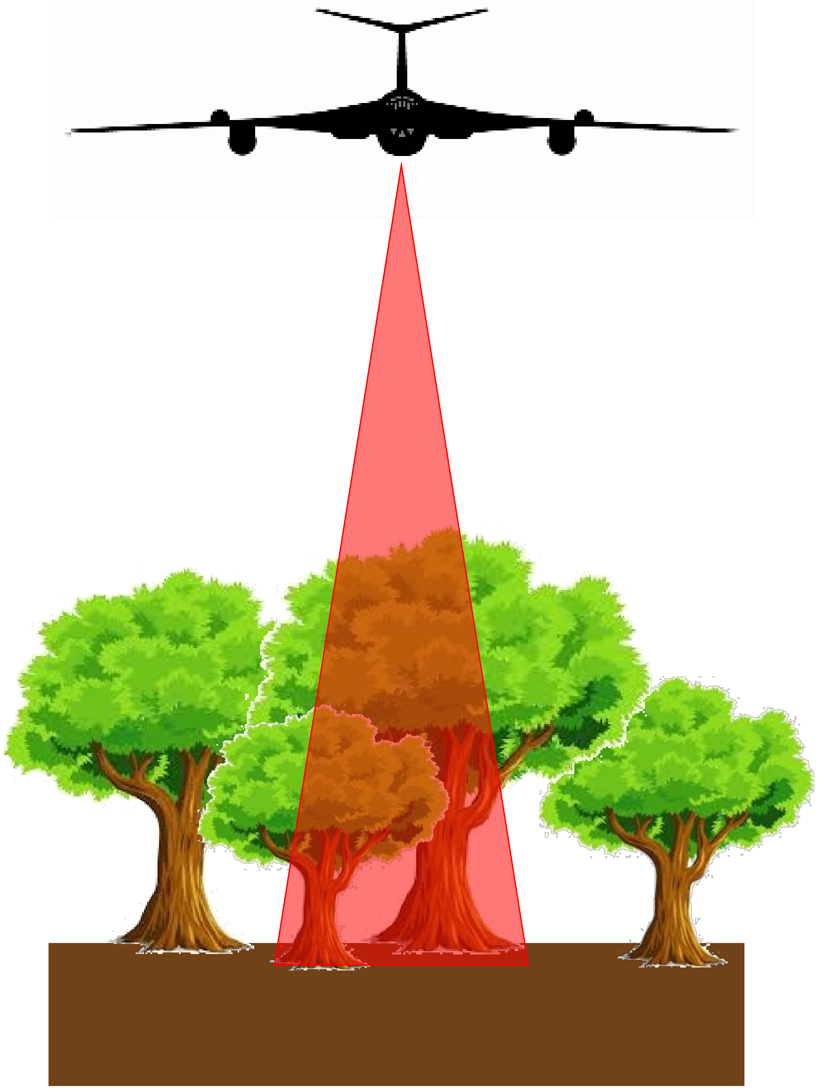
Lidar measurement

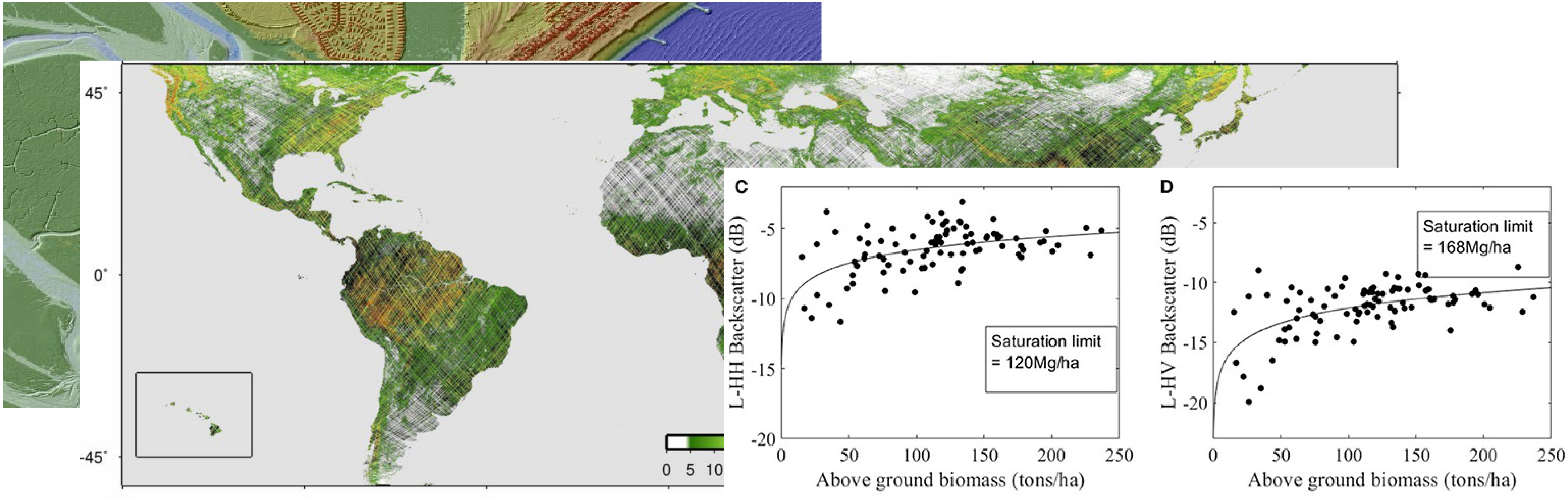




Lidar data products

Allows unbiased, non-saturating measurements of:

- Bare-Earth topography (even in complex environments)
- Tree height, vegetation density and biomass



Musthafa, M. and Singh, G., 2022. Improving Forest Above-Ground Biomass Retrieval Using Multi-Sensor L-and C-Band SAR Data and Multi-Temporal Spaceborne LiDAR Data. Front. For. Glob. Change, 5, p.822704.

Spaceborne lidar missions

NASA LITE: 1994

- Technology demonstrator

NASA ICESat/GLAS: 2003-2009

- Ice elevation and volume

NASA Calipso/CALIOP: 2006-2019+

- Cloud profiles

NASA CATS: 2015-2017

- Cloud profiles

ESA Aeolus/ALADIN: 2018-2021+

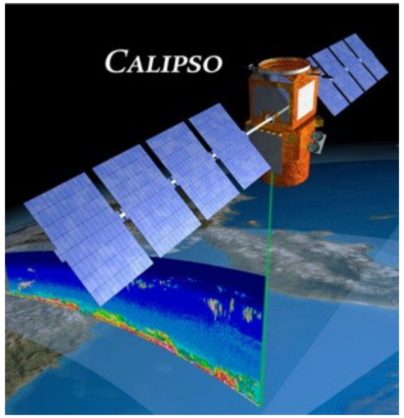
- 3D wind speed

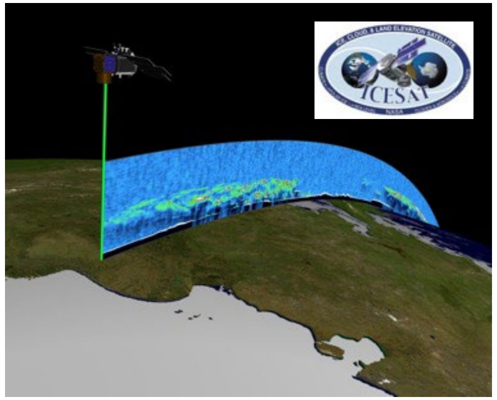
NASA ICESat-2/ATLAS: 2018-2021+

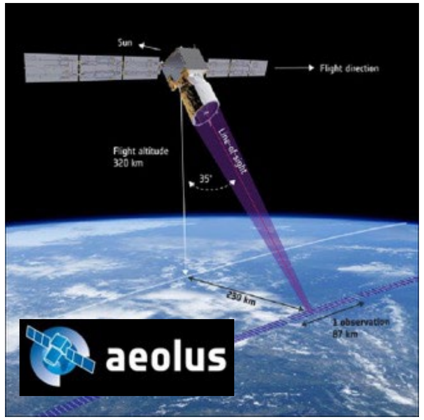
- Ice elevation and volume

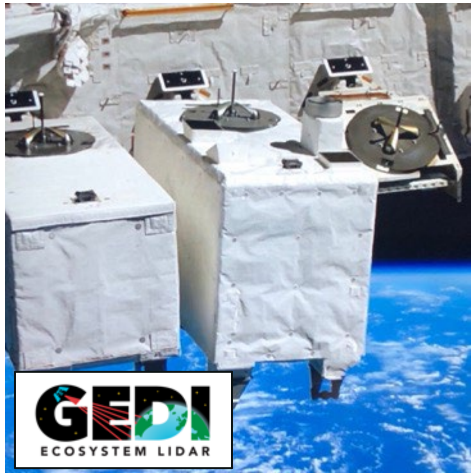
NASA GEDI: 2018-2021+

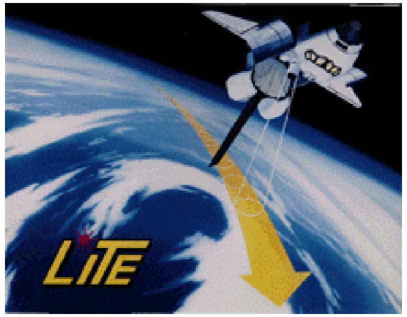
- Forest biomass and structure



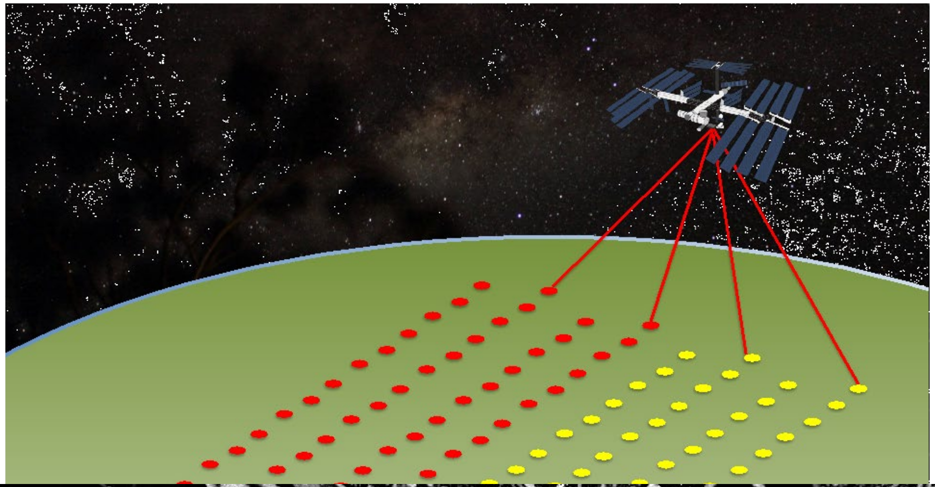


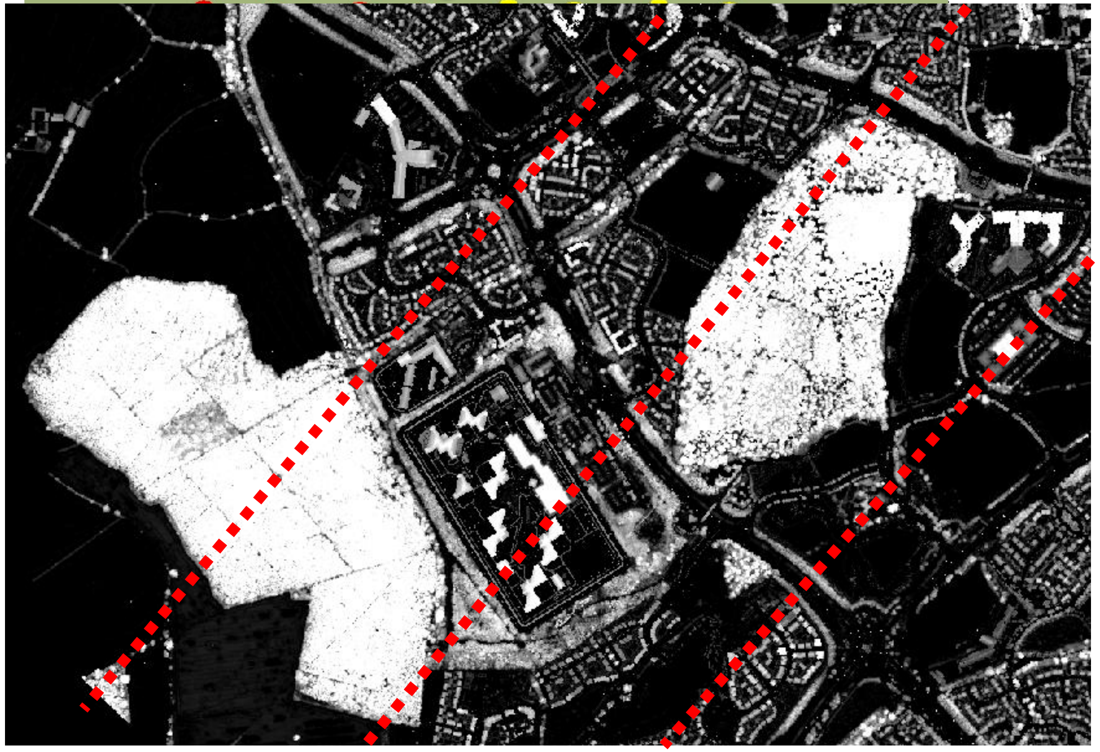






Lidar coverage





Sparse coverage limits applications

- Coarse resolution inference (forests, ice mass)

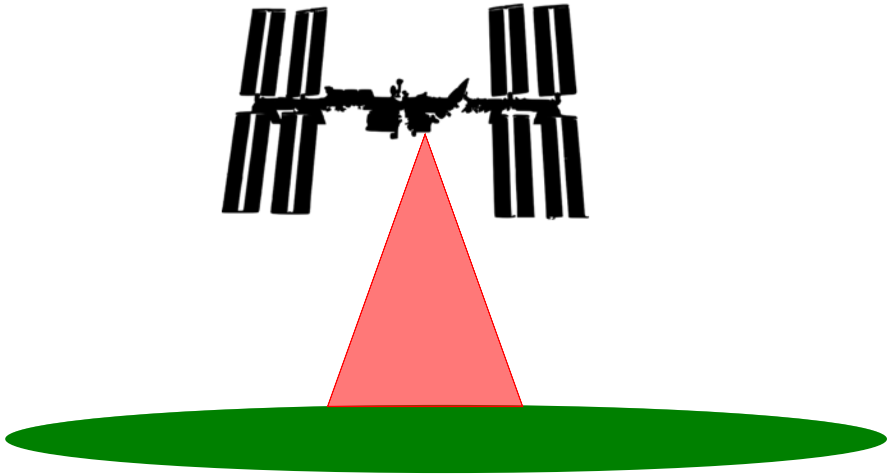
Too coarse to allow

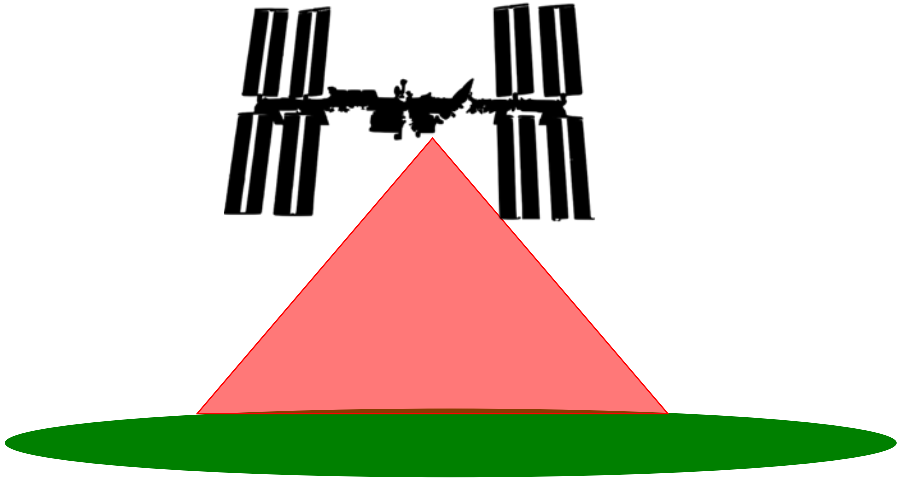
- Continuous mapping
- Flood modelling
- Anything in urban areas
- Train line monitoring
- Commercial forestry

Sparse sampling leads to uncertainty

- Complicates robust change detection

Increasing lidar coverage



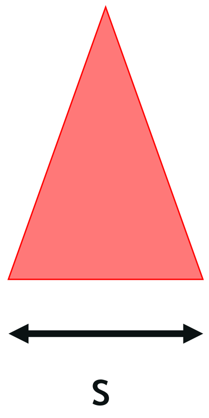


Continuous coverage satellite lidar would be…

- An incremental technology improvement
- A step change in data applications

Increasing lidar coverage

$$s = \frac{P_{pay} L_e}{E_{det}} \frac{A}{2\pi h^2} Q \rho \tau^2 \frac{r^2 (R+h)^{\frac{3}{2}}}{R\sqrt{GM}}$$



Which parts could we adjust to maximise coverage per unit cost?

- **Instrument**: Laser and detector efficiencies improved with new photonics?
- **Platform**: Maximise payload power and telescope area per unit cost?
- **Processing**: Reduce energy requirements with signal processing?

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Research

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Requirements for a global lidar system: spaceborne lidar with wall-to-wall coverage

Steven Hancock[1], Ciara McGrath[2], Christopher Lowe[2], Ian Davenport[1] and Iain Woodhouse[1]

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ORIGINAL PAPER

Investigation of very low Earth orbits (VLEOs) for global spaceborne lidar

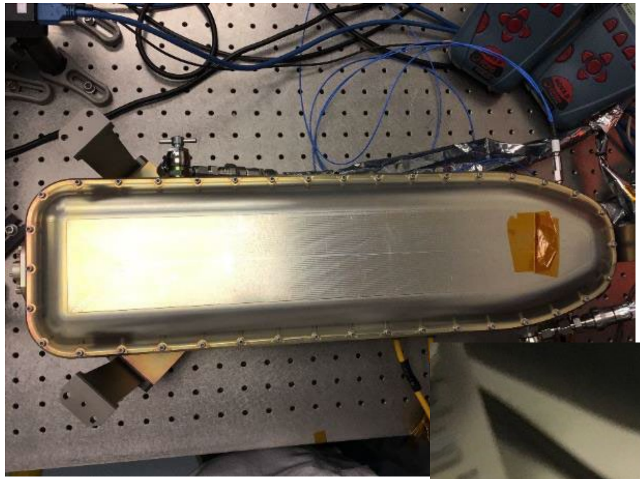
Ciara McGrath[1] · Christopher Lowe[1] · Malcolm Macdonald[1] · Steven Hancock[2]

Received: 27 August 2021 / Revised: 23 December 2021 / Accepted: 28 January 2022

Lasers

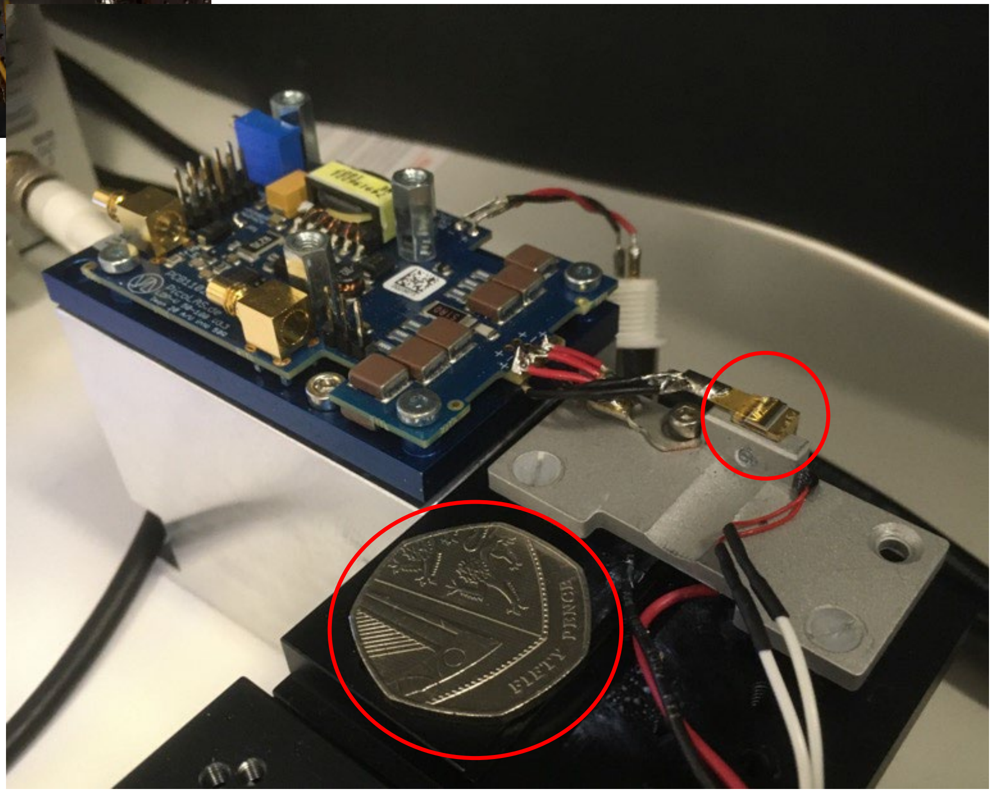
Laser modes considered

- Solid-state lasers:
  - Flight heritage
  - High peak powers (1000's kW)
  - Efficiencies of 5-8%
  - Large size

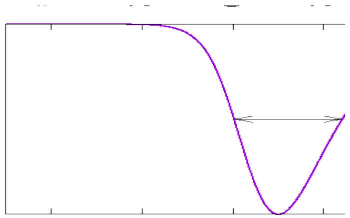


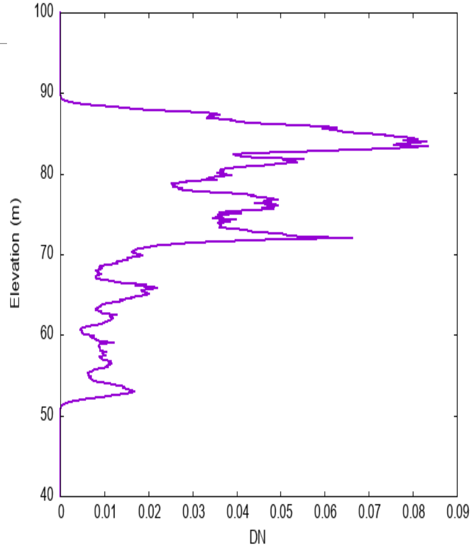
Laser modes considered

- Tapered laser diodes:
  - New technology
  - Low peak powers (~5 W)
  - High electric to optical efficiencies of around 45%
  - Small size
  - Simple

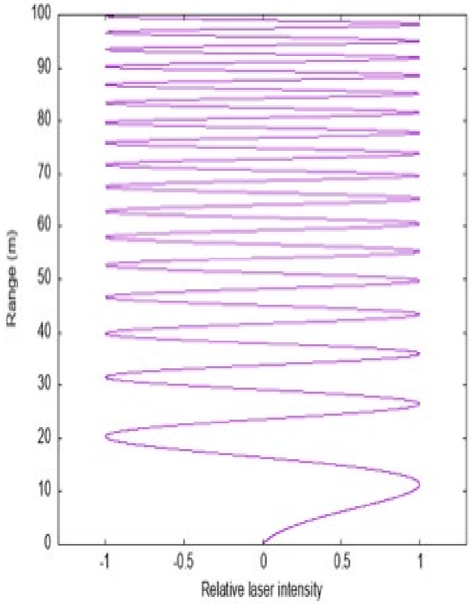


Laser source modes

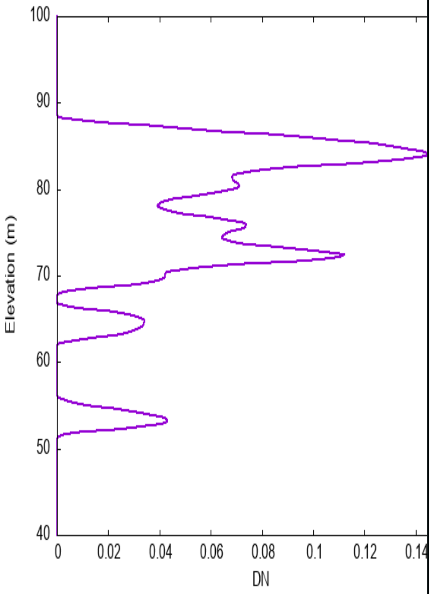


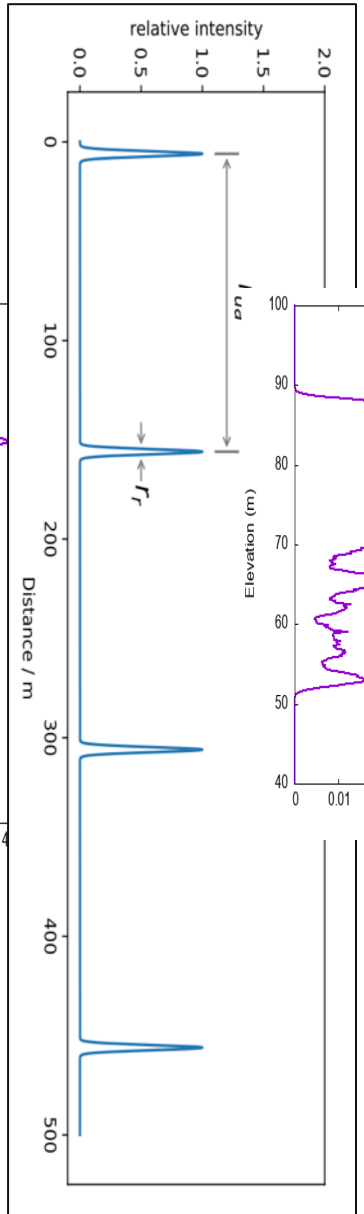


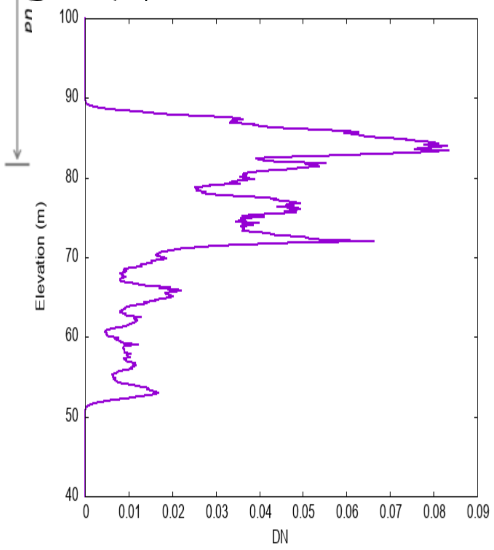
Solid-state laser pulse. 100's kW



Diode laser, pulse compressed lidar (<=15 W)







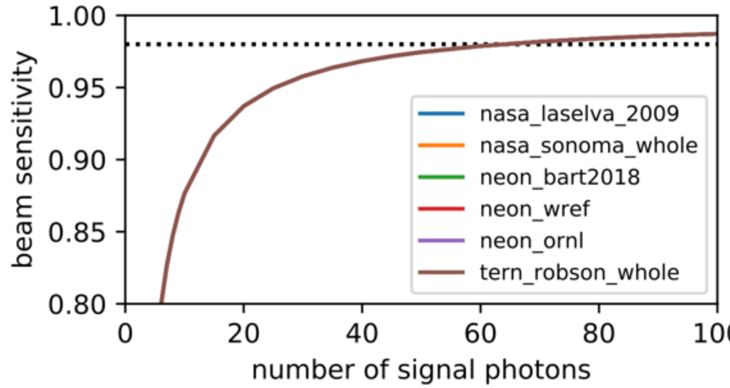
Diode laser pulse-train (<= 15W)

Laser source requirements

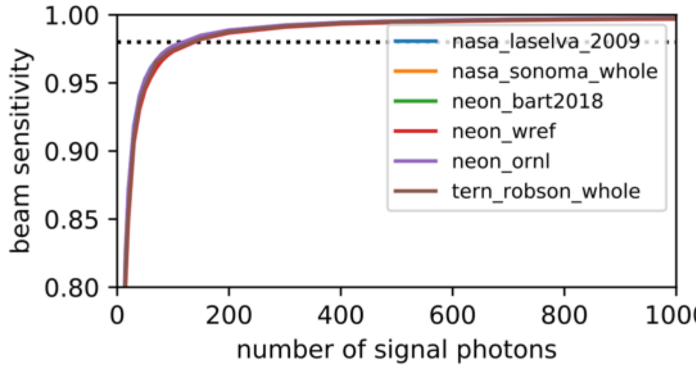
Source	solid-state		diode	
Modality	single pulse		pulse train	PCL
Detector	full waveform	photon counting	photon counting	photon counting
scenario conditions				
Q	0.58	0.31	0.58	
L_e	0.11		0.25	
N_{rep}	1		4 000	
$\Delta\lambda$	0.7 nm	30 pm	1 nm	
T	≈ 1 µs	≈ 1 µs	4 ms	
at 98% sensitivity				
N_{photons}	1 500[a]	60	115	11 400
N_{noise}	n/a	0.02	5.3	8.4
E_{det}	0.28 fJ	0.014 fJ	0.027 fJ	2.66 fJ
E_{shot}	2.6 mJ[b]	0.25 mJ	0.25 mJ	25.2 mJ
P_{peak}	79.7 kW[b]	7.5 kW	1.9 W	14.9 W
P_{avg}	0.66 W[b]	0.06 W	0.06 W	6.3 W
swath	553 m	5898 m	13 085 m	132 m
N_{sat}	4	1	1	15

[a] This number is calculated from the known E_{det} and wavelength of GEDI.

[b] The actual values on GEDI are slightly higher at $E_{\text{shot}} = 5\,\text{mJ}$, $P_{\text{peak}} = 160\,\text{kW}$ and P_{av} inefficiencies.



Solid-state, photon-counting



Diode, pulse-train

remote sensing

MDPI

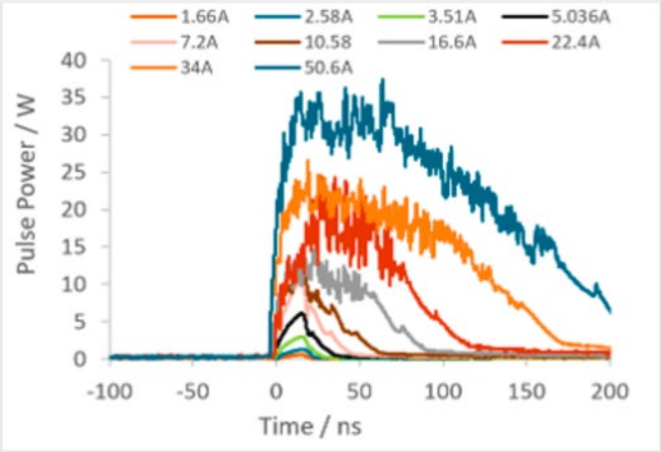
Article

Assessing Novel Lidar Modalities for Maximizing Coverage of a Spaceborne System through the Use of Diode Lasers

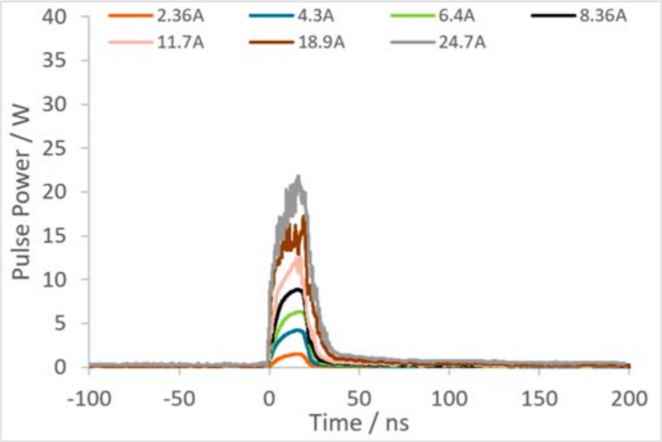
Johannes N. Hansen [1,*], Steven Hancock [1], Ludwig Prade [2], Gerald M. Bonner [2], Haochang Chen [2], Ian Davenport [1], Brynmor E. Jones [2] and Matthew Purslow [1]

https://www.mdpi.com/2072-4292/14/10/2426

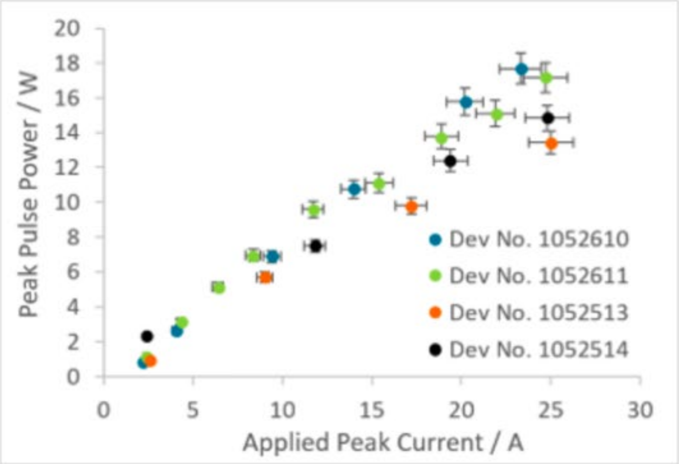
Laser power testing



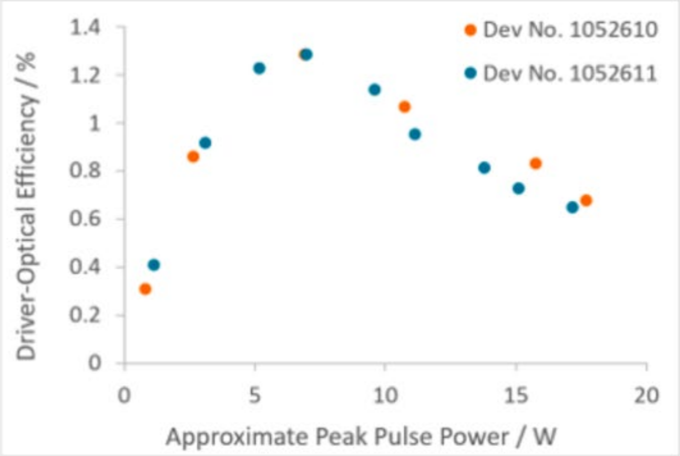
(a) Broadened Pulses



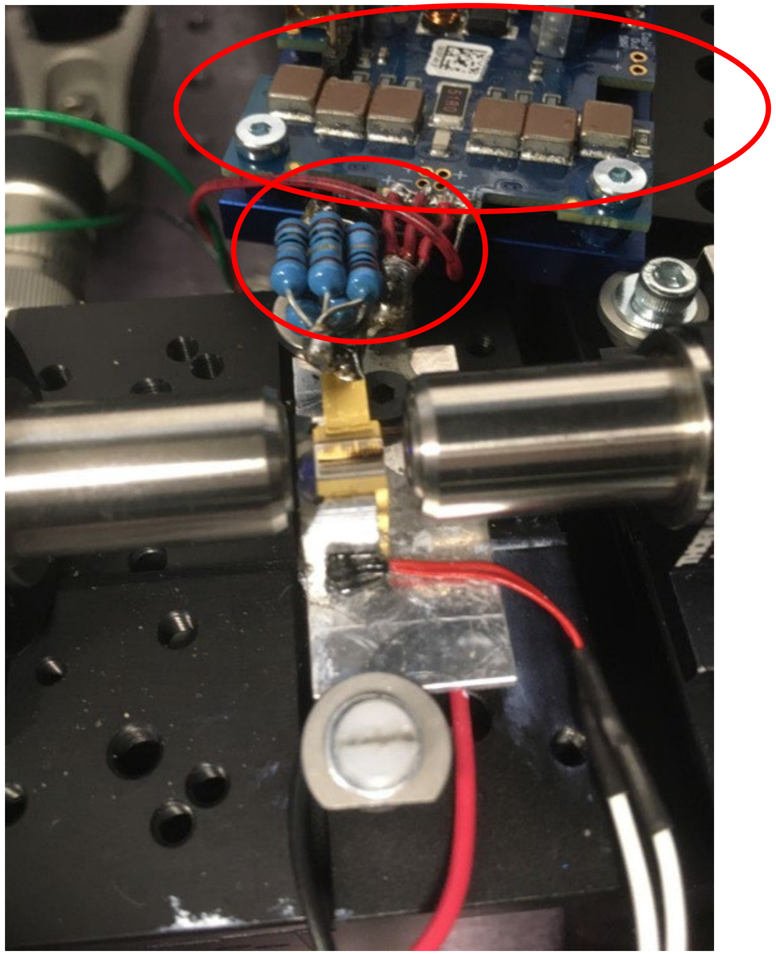
(b) Narrow Pulses



(a) Peak power at 20 ns



(b) Efficiency



Optics and platform

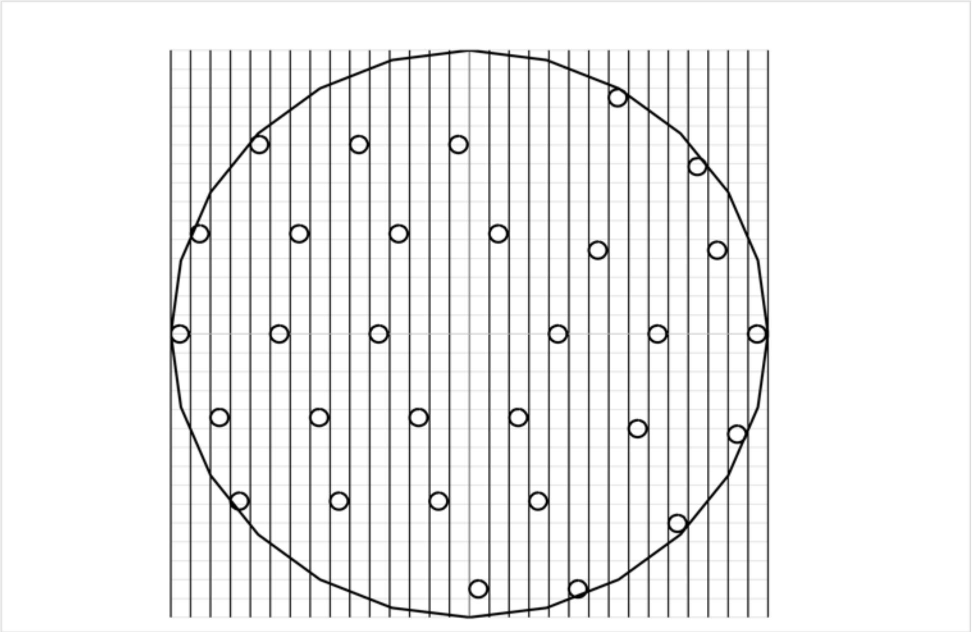


Figure 1-1: A potential arrangement of 30x 30m spots inside a 1km diameter, with a single spot in each vertical stripe to create a comb. The implied maximum spot separation is approximately 150m

Conclusions

Global lidar with continuous coverage is possible

- Diode laser can be used, although efficiency needs raising to make them competitive
    - Efficiency needs increasing and then TRL raising

- 150 kg satellite seems the preferred option
    - Most “cost-effective” way to generate lidar swath
    - Lower cost per platform reduces risk per launch
    - May allow deployable optics, further adding margin/lowering cost

- How best to fund the route to launch?
    - 1-2 year technology development project fo
    - 1-2 year project for deployable optics

- Alternatives?
    - Sampling mission (NASA solid-state?)
    - Data fusion (lidar-SAR?)

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Research

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