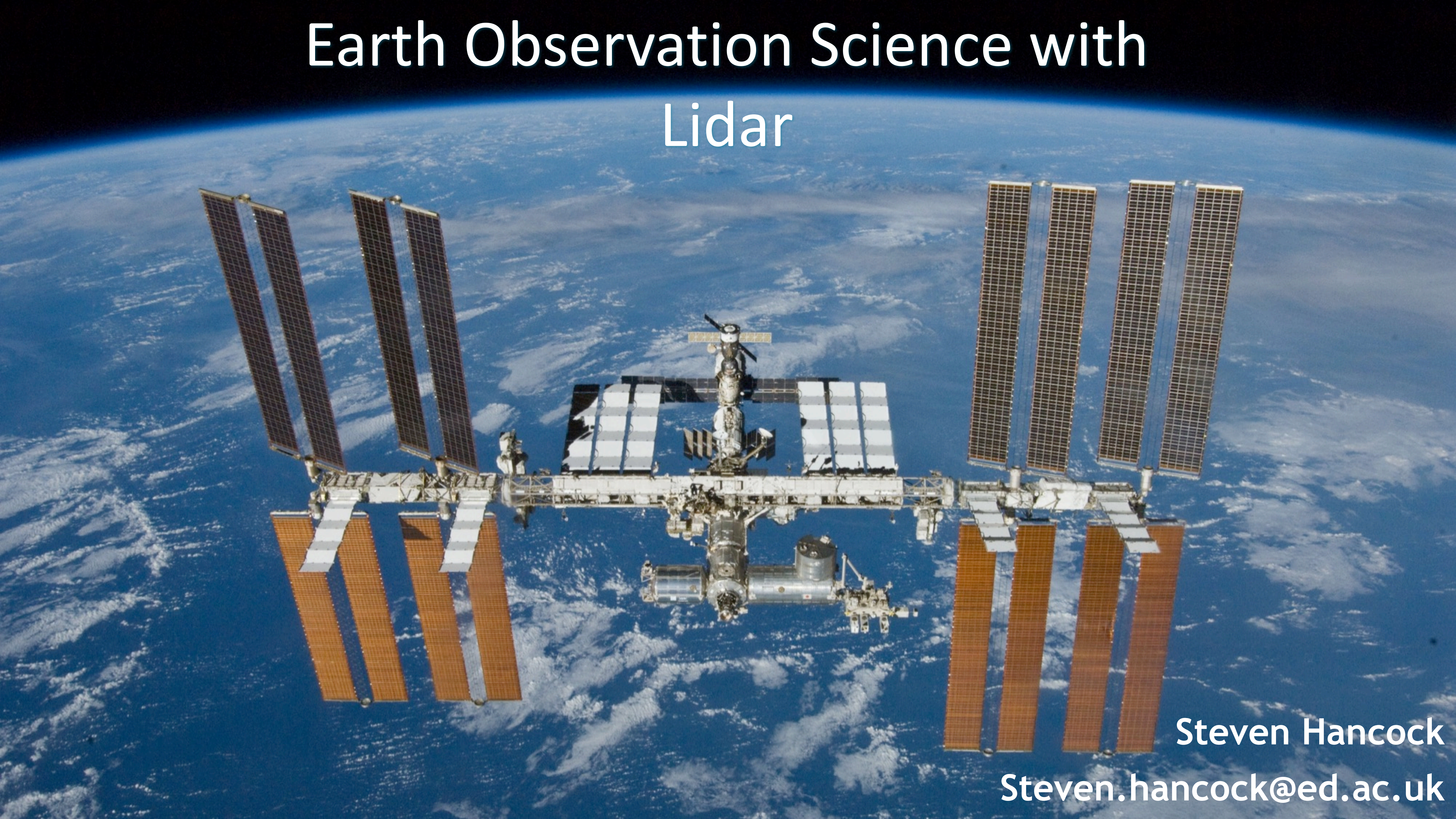
Earth Observation Science with Lidar



Steven Hancock

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What can lidar measure?

Land surface:

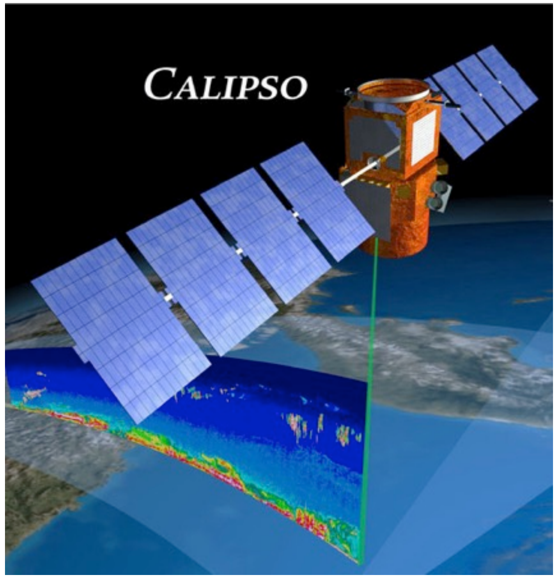
- Elevation
- Vertical structure
- Ice/water discrimination (?)

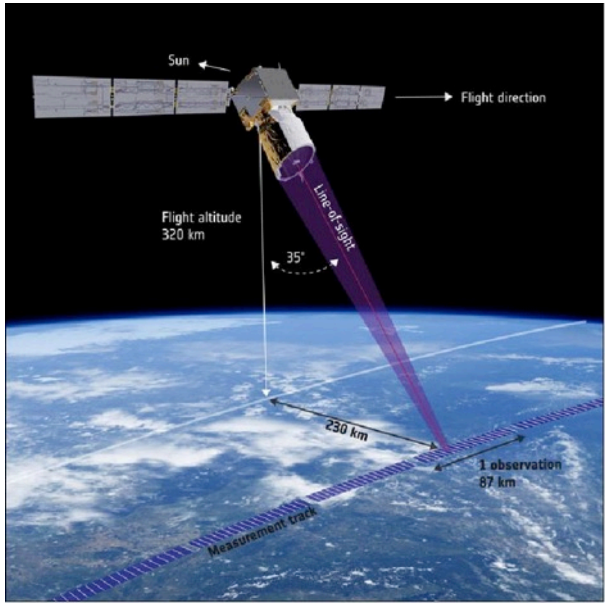
Atmosphere:

- Aerosol optical depth
- Particle properties
- Trace gas concentration (?)
- Wind speed

Ocean (?)

- Surface elevation
- Bathymmetry





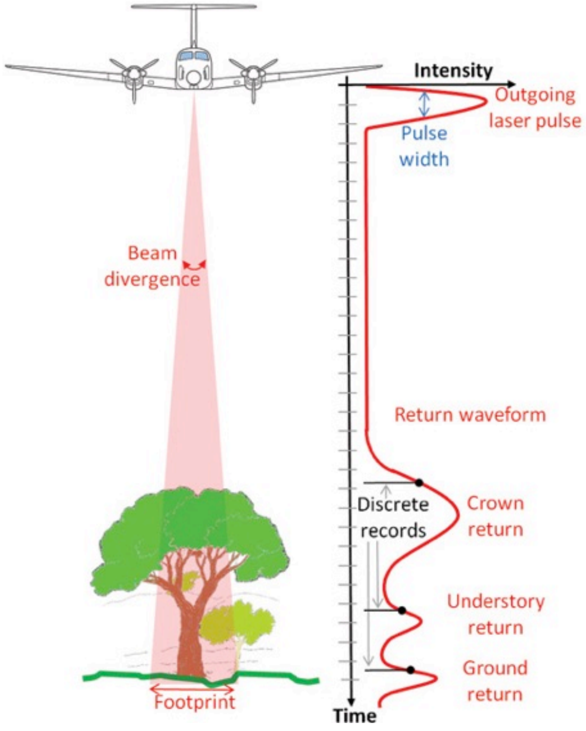
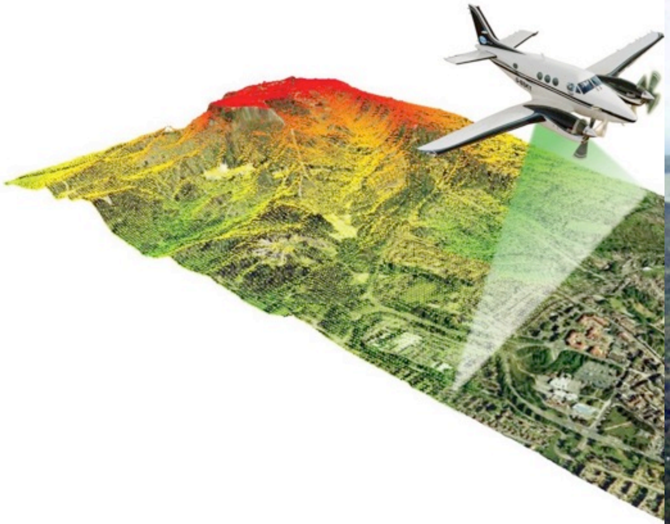
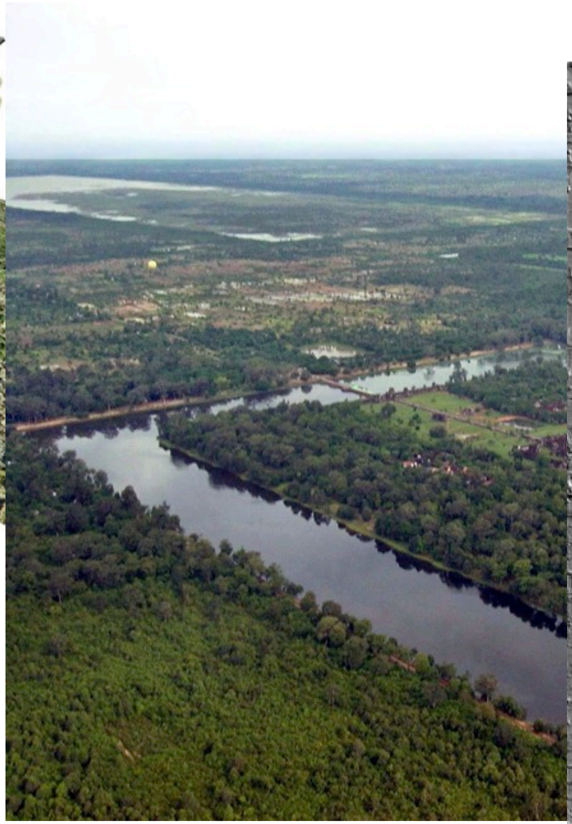
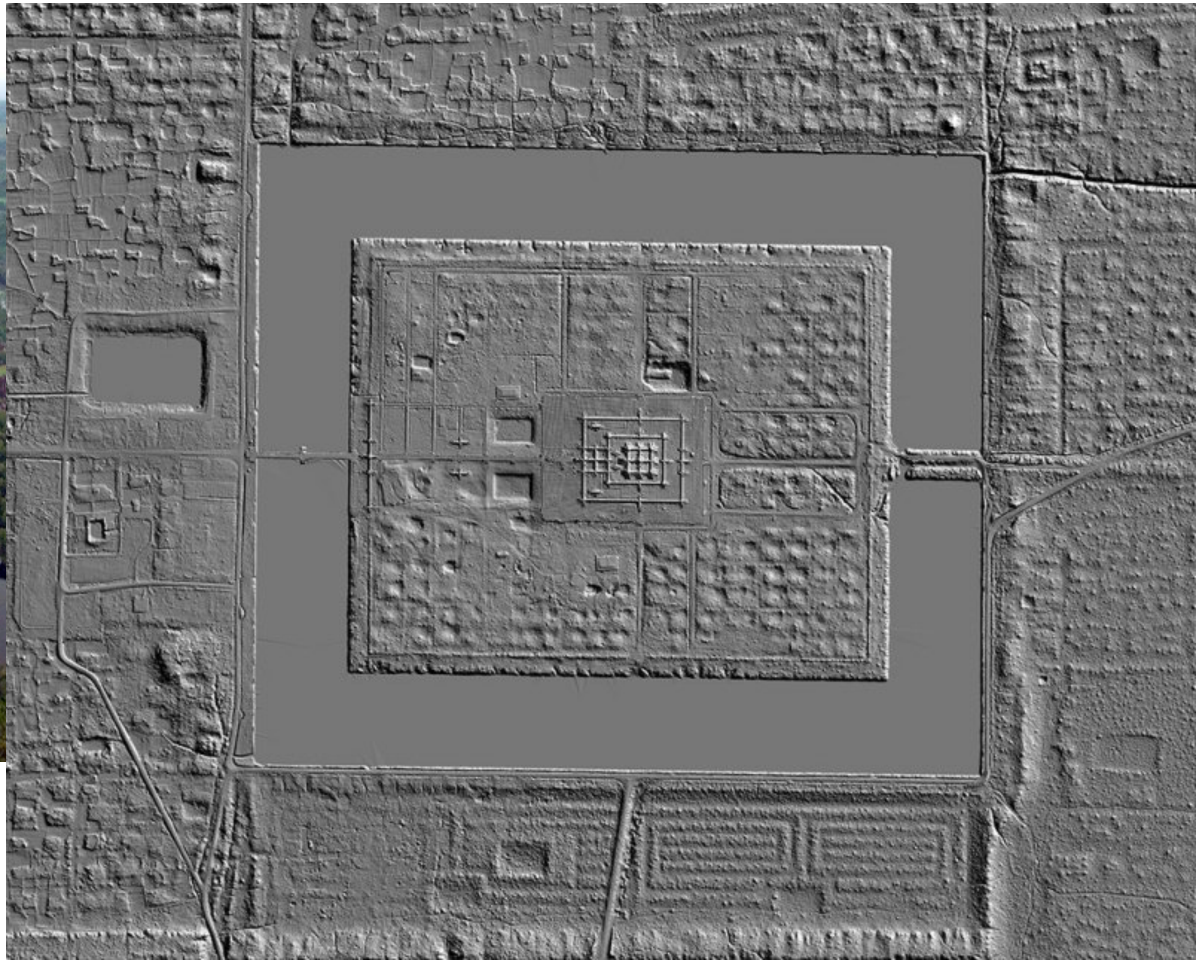


Figure by R. Dubayah

Lidar altimetry for land surface

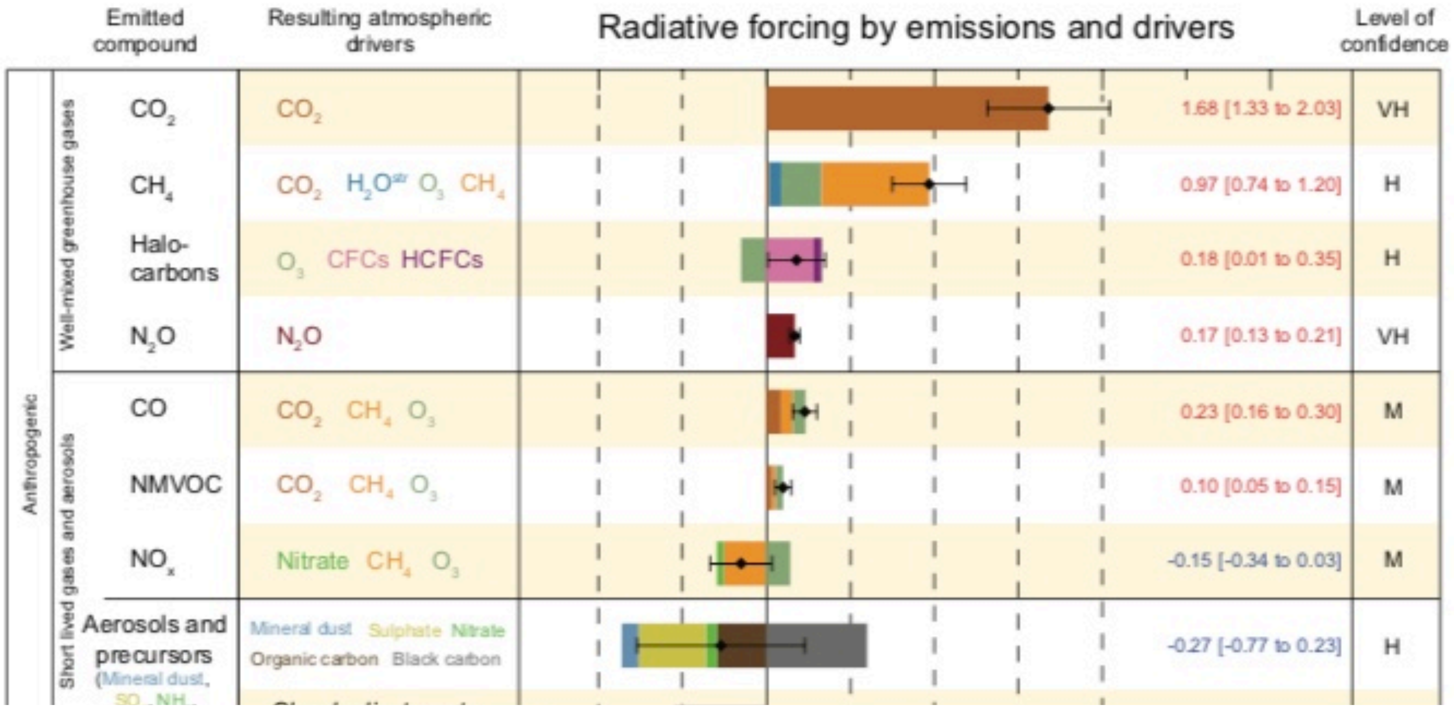






Science unknowns

IPCC report, AR5 2013

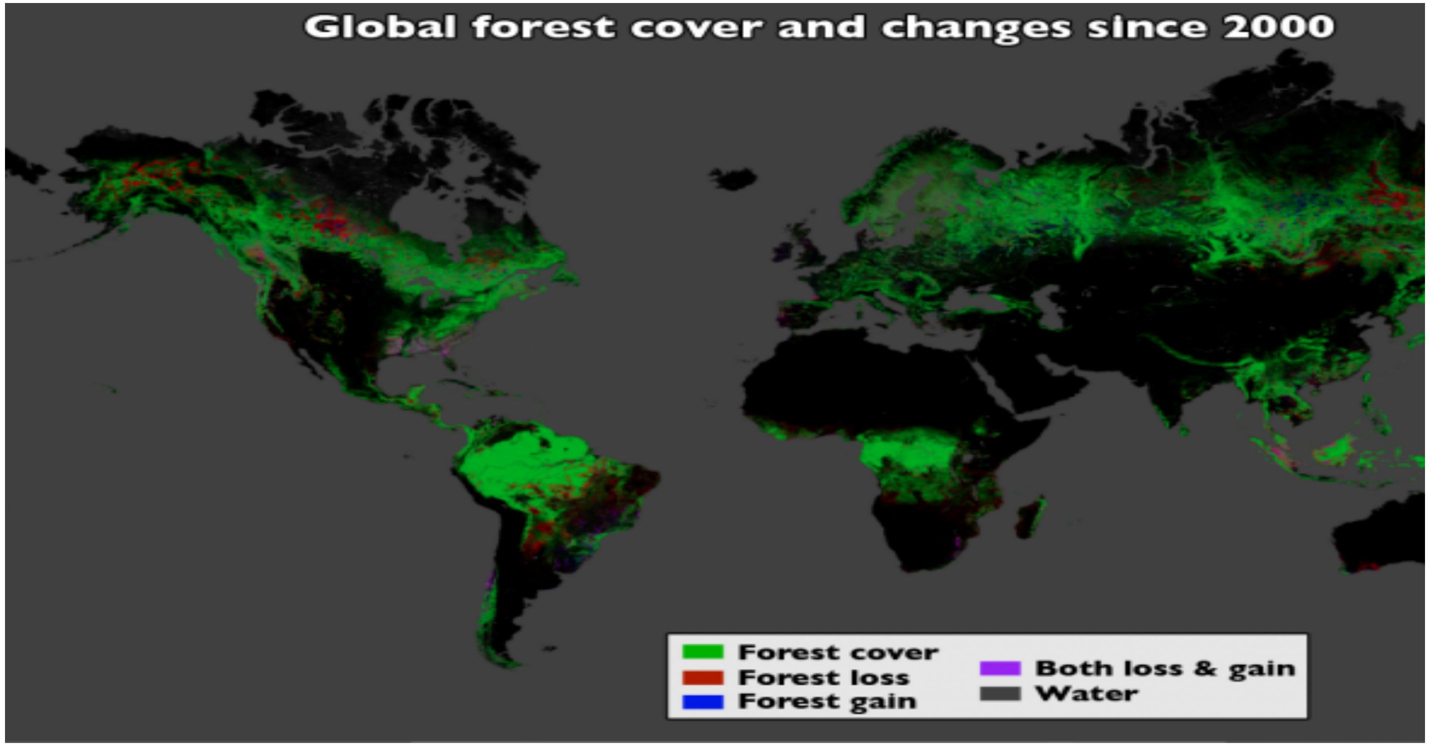


- The average rate of ice loss from the Antarctic ice sheet has *likely* increased from 30 [–37 to 97] Gt yr^{-1} over the period 1992–2001 to 147 [72 to 221] Gt yr^{-1} over the period 2002 to 2011. There is *very high confidence* that these losses are mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica. {4.4}

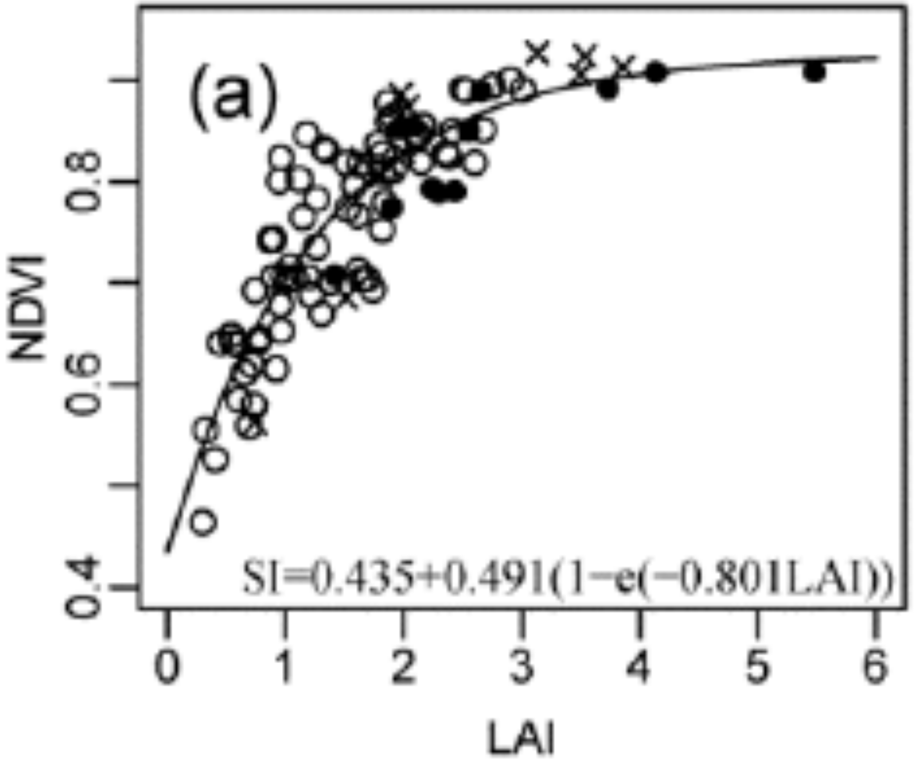
- Annual CO_2 emissions from fossil fuel combustion and cement production were 8.3 [7.6 to 9.0] GtC[12] yr^{-1} averaged over 2002–2011 (*high confidence*) and were 9.5 [8.7 to 10.3] GtC yr^{-1} in 2011, 54% above the 1990 level. Annual net CO_2 emissions from anthropogenic land use change were 0.9 [0.1 to 1.7] GtC yr^{-1} on average during 2002 to 2011 (*medium confidence*). {6.3}

Land surface remote sensing

Passive optical and SAR have limitations compared to lidar.



Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A.A., Tyukavina D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-reso global maps of 21st-century forest cover change. *science*, *342*(6160), pp.850-853.



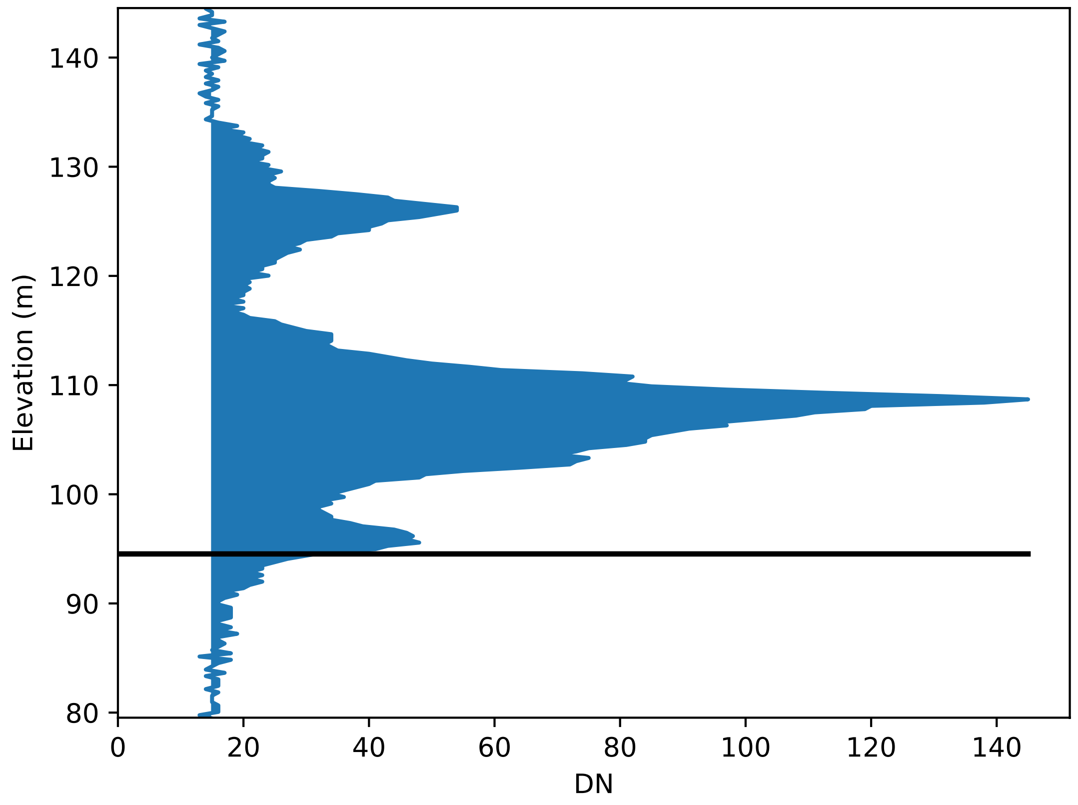
Tanaka et al, 2015. Spectral index for quantifying leaf area index of winter wheat by field hyperspectral measurements: a case study in gifu prefecture, central Japan. *Remote Sensing*, *7*(5), pp.5329-5346.

Lidar altimetry for land surface

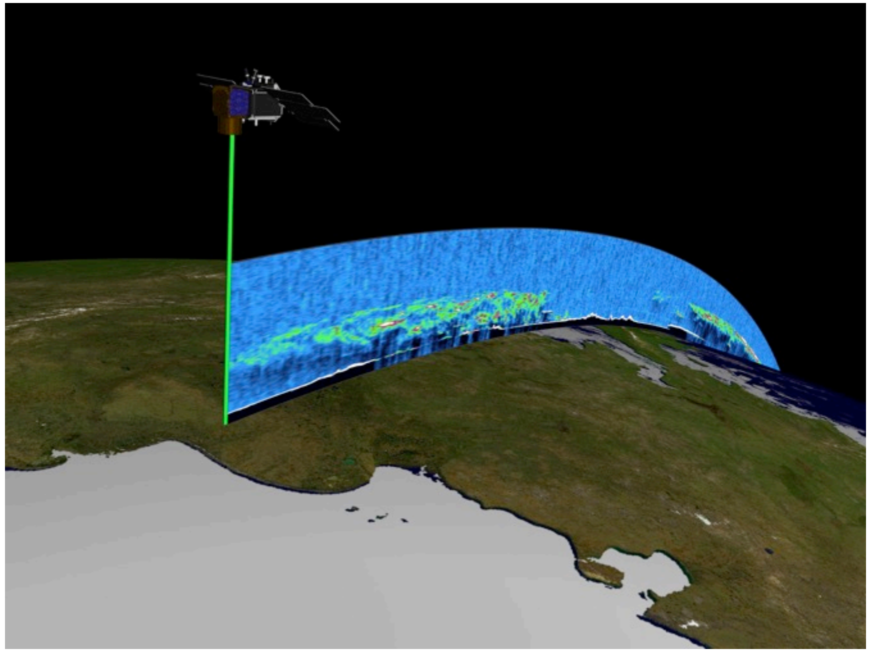
Lidar has some unique advantages over other techniques

- Range resolved allows separation of returns:
  - Bare Earth DEM
  - Diffuse target height

- Can penetrate very dense canopies

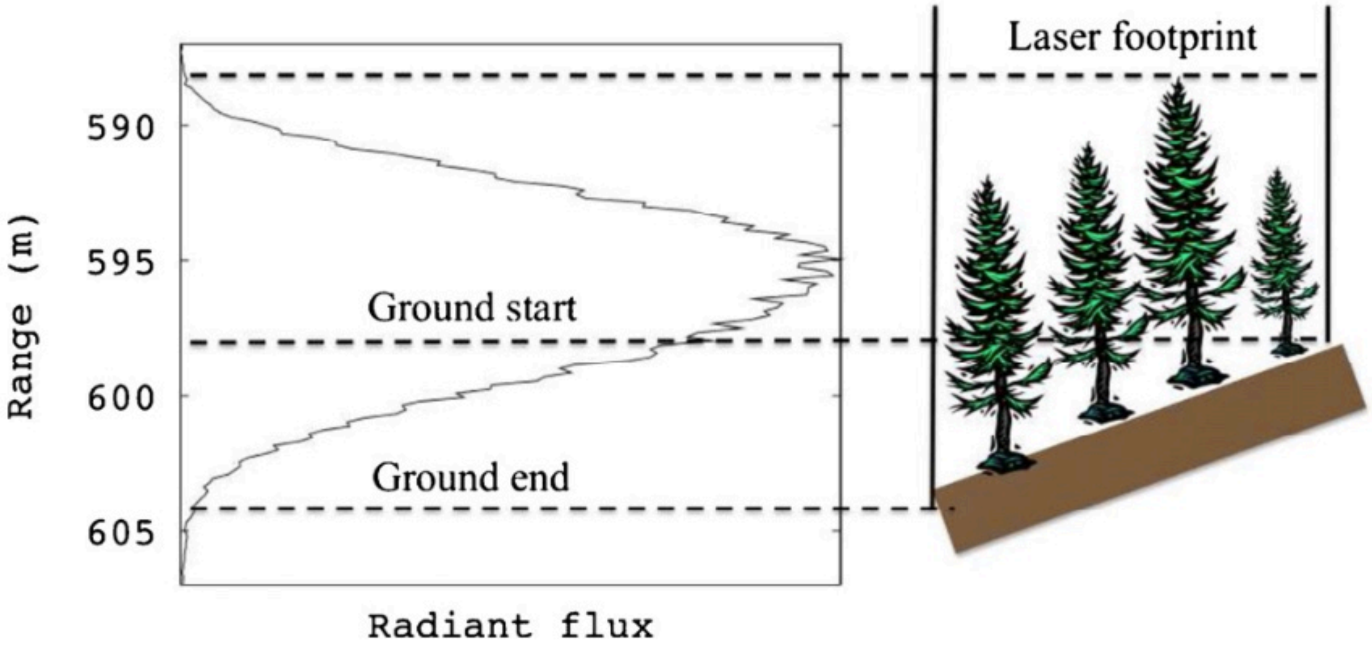


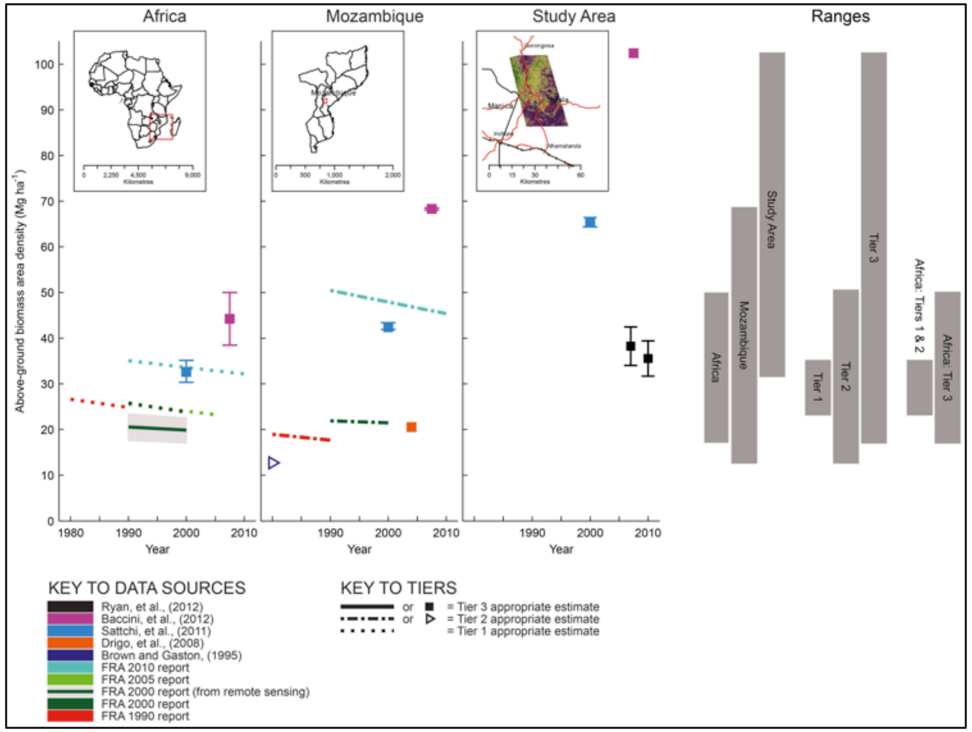
Lidar missions: ICESat/GLAS



- **ICESat/GLAS (2003-2009): High power, low coverage**
  - 94^{o} orbit at ~600 km altitude
  - Single track (many kms between tracks), 1064 nm
  - 40 Hz (~200 m between footprints)
  - ~100 mJ laser (degraded to 25 mJ by mission end)
  - 3 lasers, firing one on at a time
  - 65-90 m diameter footprint
  - Dual wavelength, full-waveform
    - 1064 nm sampled at 15 cm for land surface
    - 532 nm sampled at ~75m for atmosphere (frequency doubled)

Lidar mapping

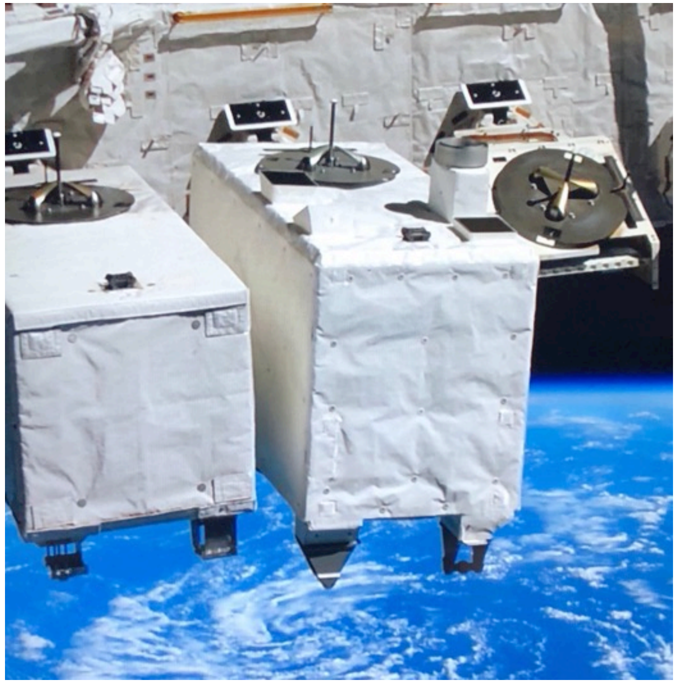


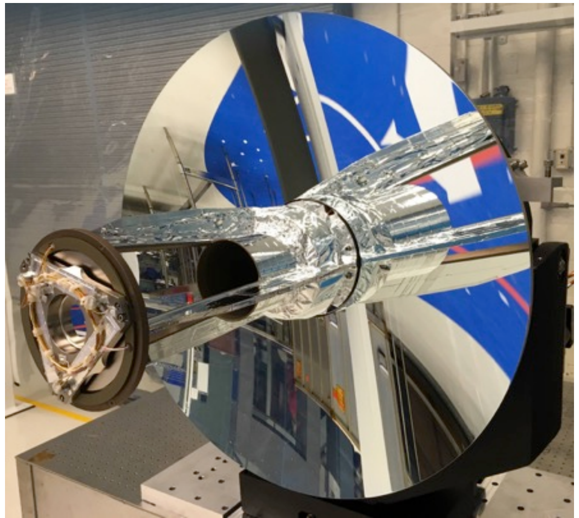


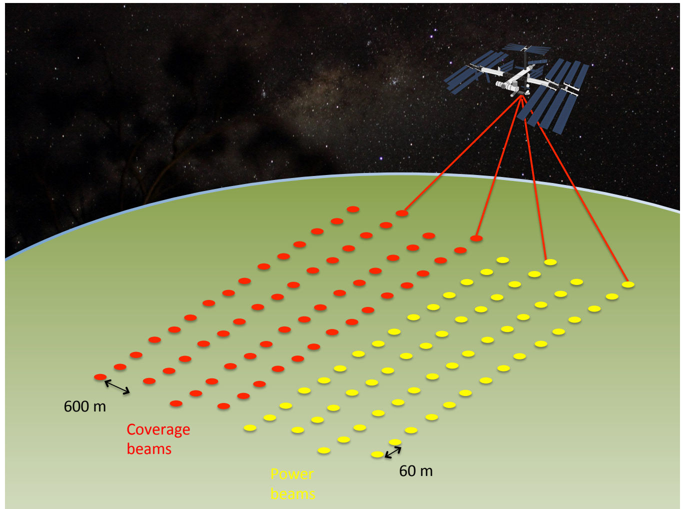
Hill, T.C., Williams, M., Bloom, A.A., Mitchard, E.T. and Ryan, C.M., 2013. Are inventory based and remotely sensed above-ground biomass estimates consistent?. *PLoS One*, *8*(9), p.e74170.

Lidar missions: GEDI

- **GEDI/ISS (2018-2020): Lower power per shot, higher coverage**
  - 51.6^{o} orbit at ~400 km altitude
  - Three lasers, two direct, one split in two
  - 242 Hz (~30 m between shots)
  - “Dithered” to give 8 ground tracks separated by 600 m
  - 10 mJ lasers (one split to ~4.6 mJ)
  - ~22 m footprint
  - 1064 nm, full waveform (15 cm sampling)

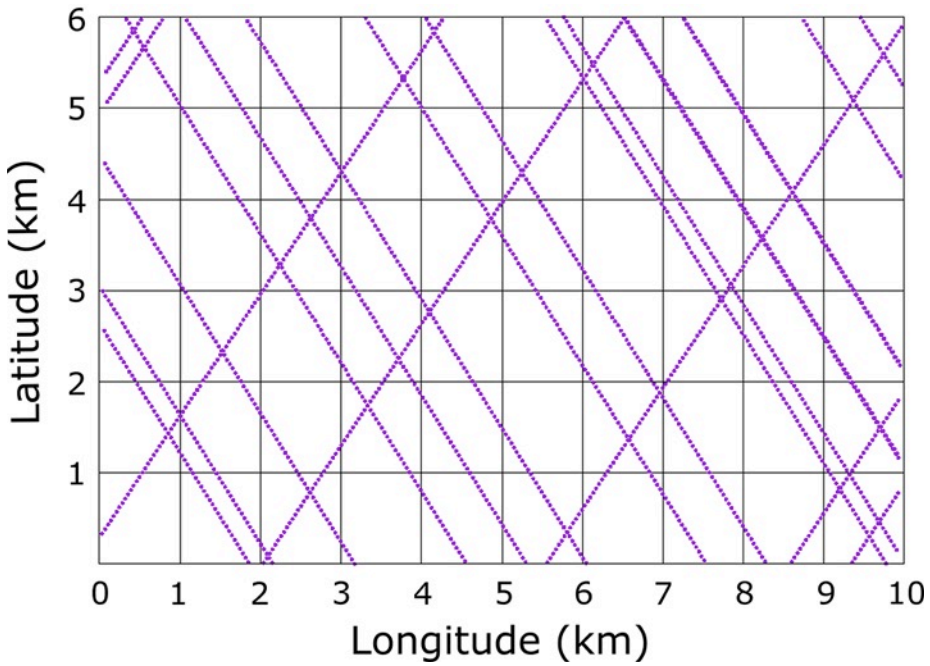






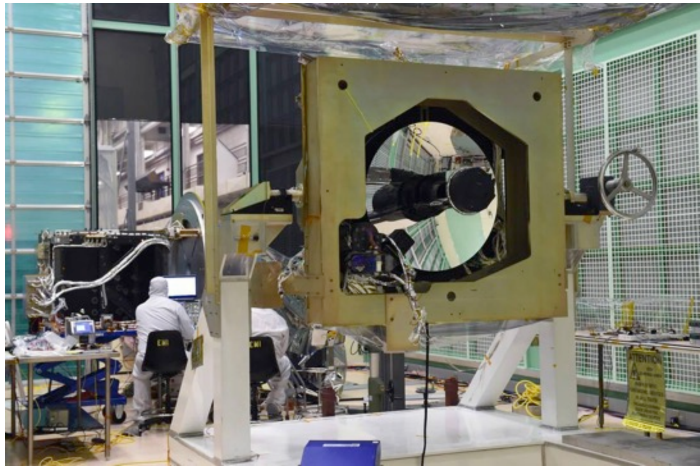
GEDI coverage

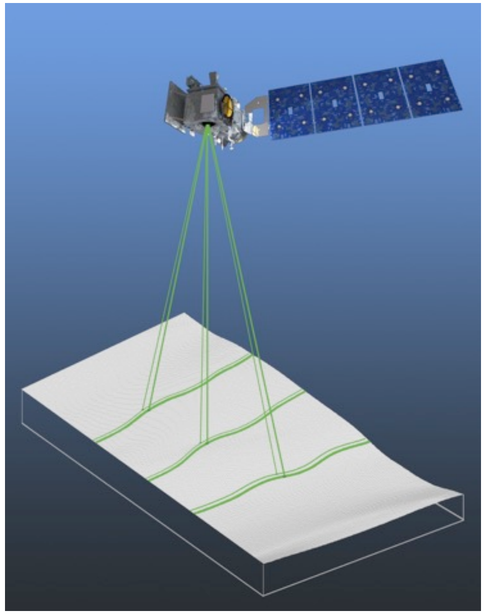
GEDI
ECOSYSTEM LIDAR



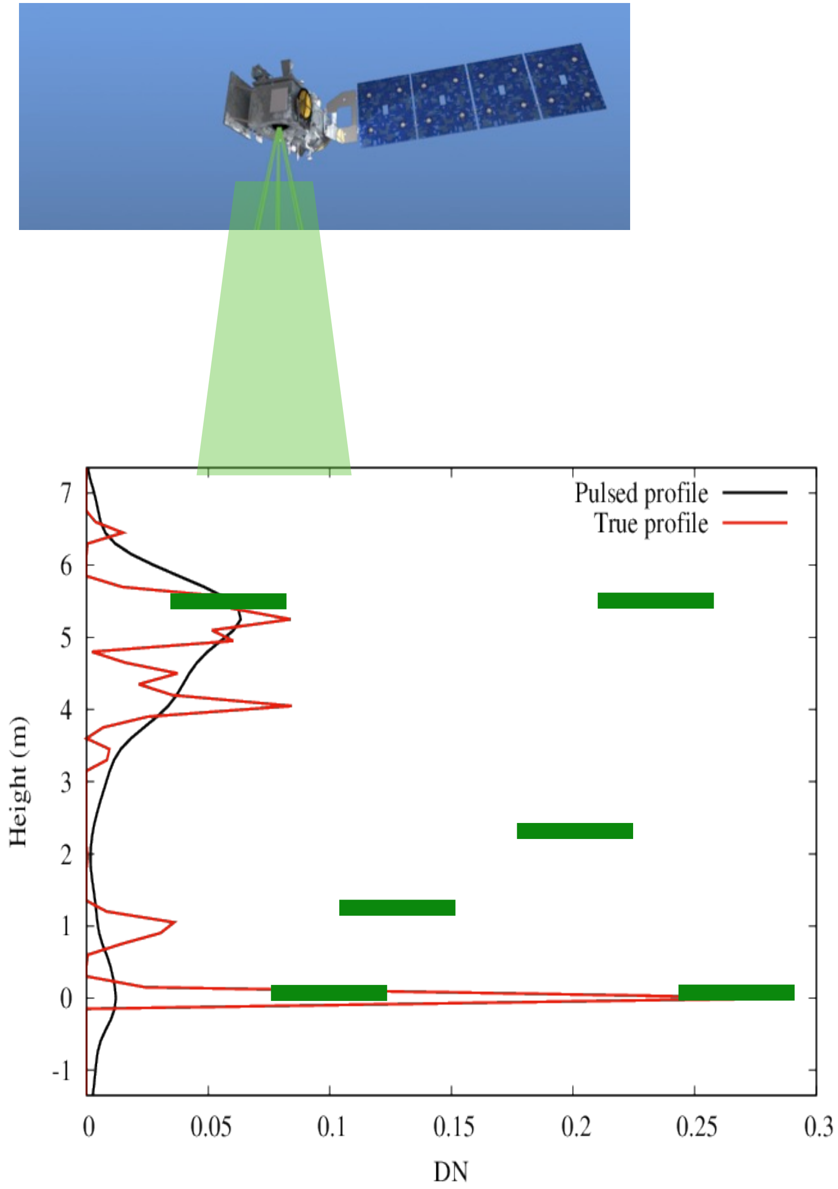
Lidar missions: ICESat-2

- **ICEsat-2/ATLAS (2018-2021+): Lower power per shot, higher coverage**
  - 92º orbit at ~400 km altitude
  - One laser split in to 6 (3 power, 3 coverage), 532 nm
  - 10 kHz (~70 cm between shots)
  - ~1.2 mJ laser (2010 estimate)
  - ~17 m footprint
  - Photon counting (~1-10 signal photons per shot, +noise)

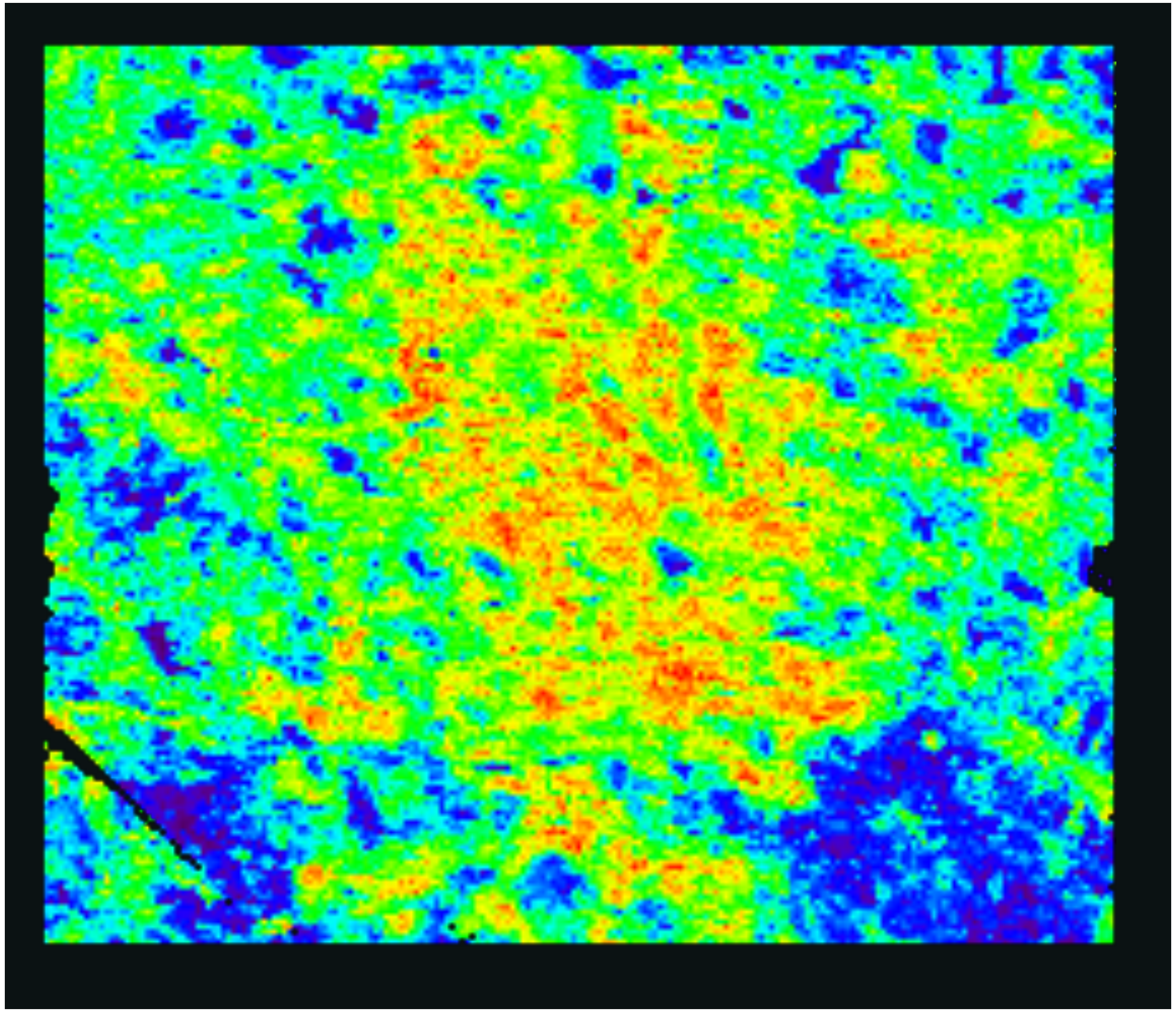


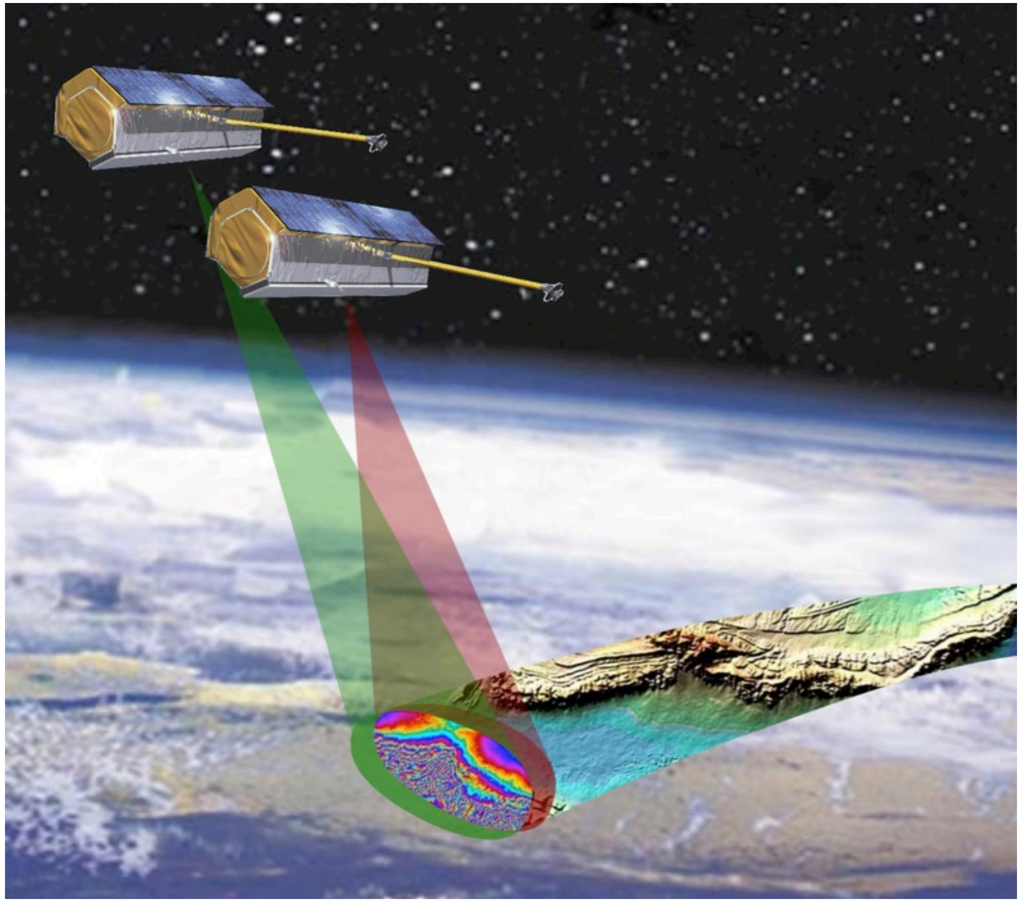


ICESat-2: Photon-counting



Data Fusion: Continuous coverage





Qi, W. and Dubayah, R.O., 2016. Combining Tandem-X InSAR and simulated GEDI lidar observations for forest structure mapping. *Remote sensing of Environment*, *187*, pp.253-266.

Atmospheric lidar: CALIPSO/CALIOP

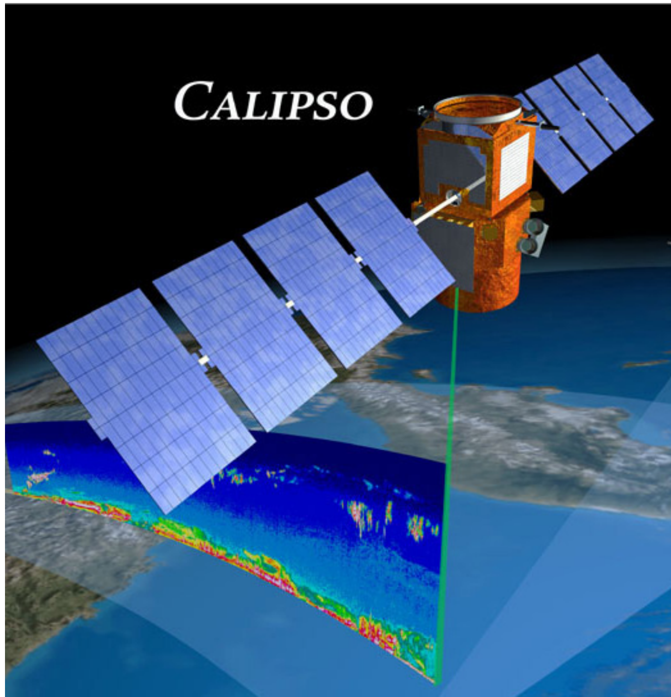
An atmospheric profiling mission, 2006->

- 110 mJ laser, 1064nm, frequency doubled to 532nm
- 20 ns pulse (6 m of blurring)
- Footprint ~70 m at ground
- Laser fires at 20 Hz (335 m between shots)
- Wide variety of return ranges, so needs high dynamic range (22 bit = 4,194,304 possible values)
- Full-waveform 30 m range resolution
- Profiles from 0-8.2 km, with averages from 8.2-30/40 km (1064nm/532nm)
- Dual polarisation detectors for 532 nm (discriminates ice from water droplets)

Data products

- Backscatter as a function of height
- Layer heights
- Cloud or aerosol (back scatter strength)
- Particle type estimation (depolarisation)
- Aerosol type (through fusion with other datasets)

https://journals.ametsoc.org/doi/full/10.1175/2009JTECHA1281.1



Atmospheric lidar: CATS

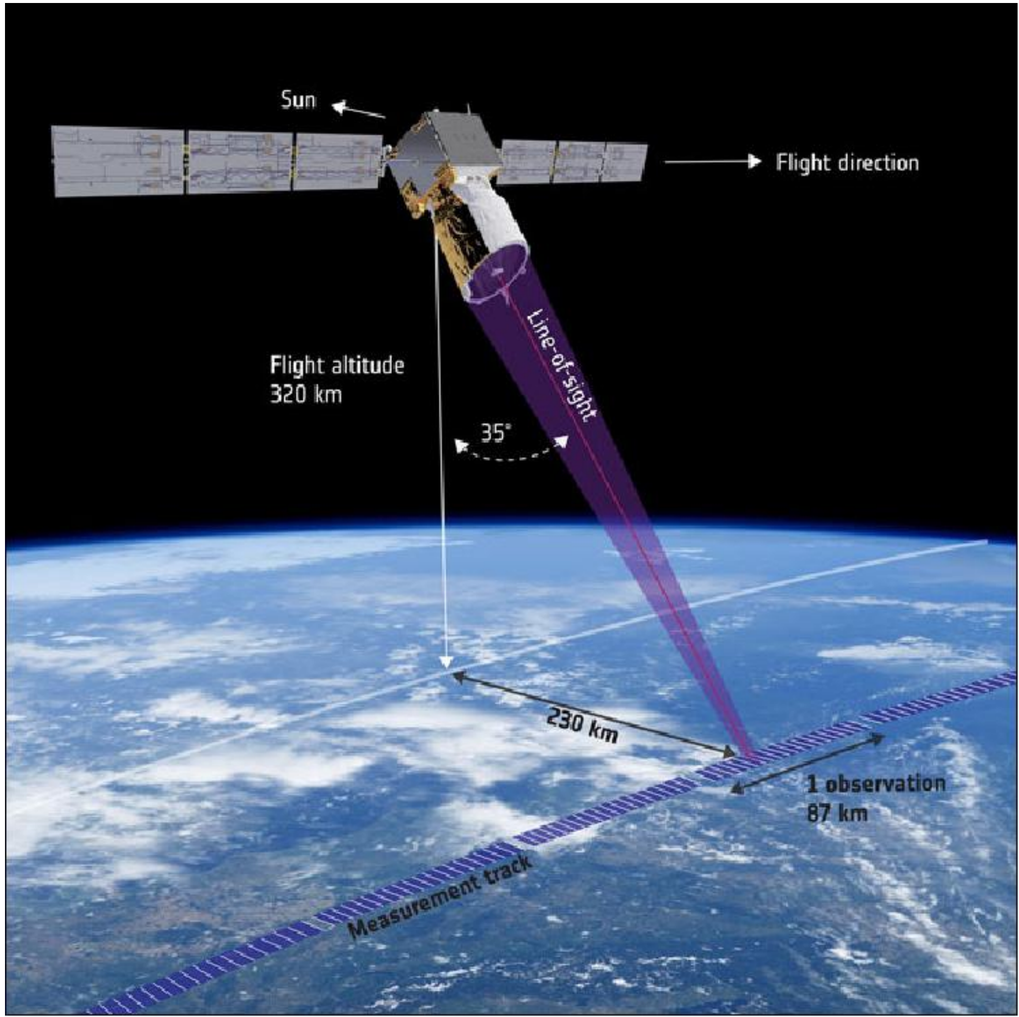
Photon counting version of CALIOP

- 2015-2017
- Similar to CALIOP but uses a photon counting detector
- Higher pulse rate. More beams.

Wind speed

Light reflecting from a moving target will be Doppler shifted

- Detect the change in returned light wavelength (range resolved)
- Measures wind velocity along laser beam vector
- Launched August 2018 for three year minimum mission
- 335 nm laser (1064 nm laser frequency tripled), 150 mJ, 100 Hz.
- Measures between 0-30 km at 500-2000m resolution



https://journals.ametsoc.org/doi/full/10.1175/2009JTECHA1309.1

What is needed?

The main issue is coverage, spatial and temporal

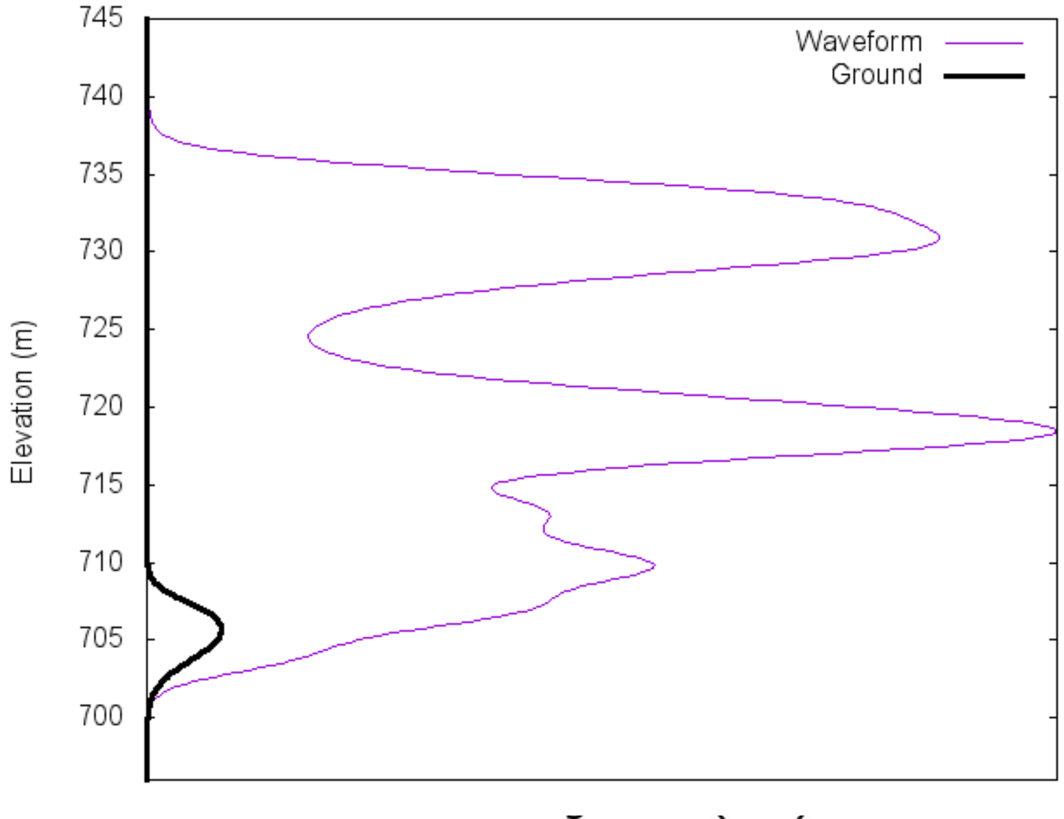
- Imaging lidar, or more beams, or more satellites (smallest lidar satellite?)
- More sensitive waveform detectors?
- Photon counting arrays, with sufficient photons for high SNR? NASA LIST?
- More of the same in 5-10 years time

Multi-wavelength

- Biochemistry
- Differentiual absorption
- Ground finding
- TLS instrument developed. Alignment challenging

Polarimetry

- Ice/water discrimination
- Cloud properties



What is needed?

Ground calibration/validation

- Available datasets
- Turnkey software solutions