Department of Geography

College of Science and Engineering

Applications of LIDAR in Environmental Science

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1st EUFAR FP7 Training Course on "ADvanced Digital Remote sensing in Ecology and earth Sciences Summer School (ADDRESSS), Tihany, Hungary, 19-28 August 2010.

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Structure of the talk

- Principles of LIDAR
- Applications of LIDAR
  - Forest mapping
  - Habitat mapping
  - Urban mapping
  - Terrain modelling
  - Earthquakes
- Conclusions

PRINCIPLES OF LIDAR

LIDAR / ALS

- LIDAR = Light Detection and Ranging
- ALS = Airborne Laser Scanning

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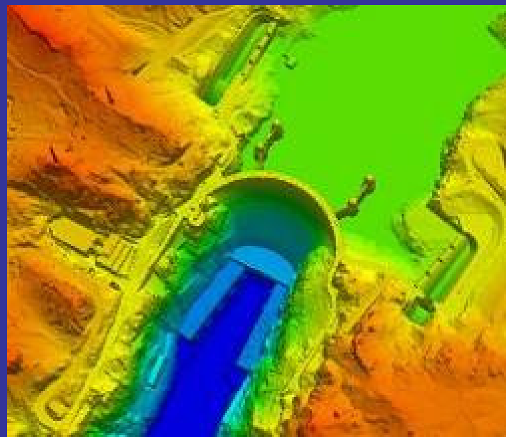
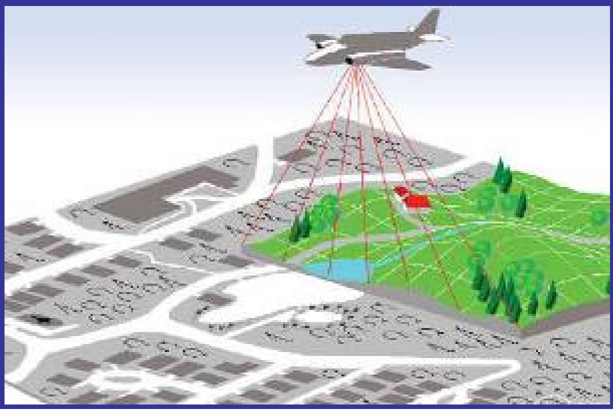
What is laser scanning?

Laser scanning is an active remote sensing technique

- Emit a pulse of polarised laser light
- Record the time taken for the light to return
- Measure the distance between object and sensor
    - Topographic data capture
    - Satellite, airborne, terrestrial platforms





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Airborne LIDAR

NERC Airborne Remote Sensing Facility

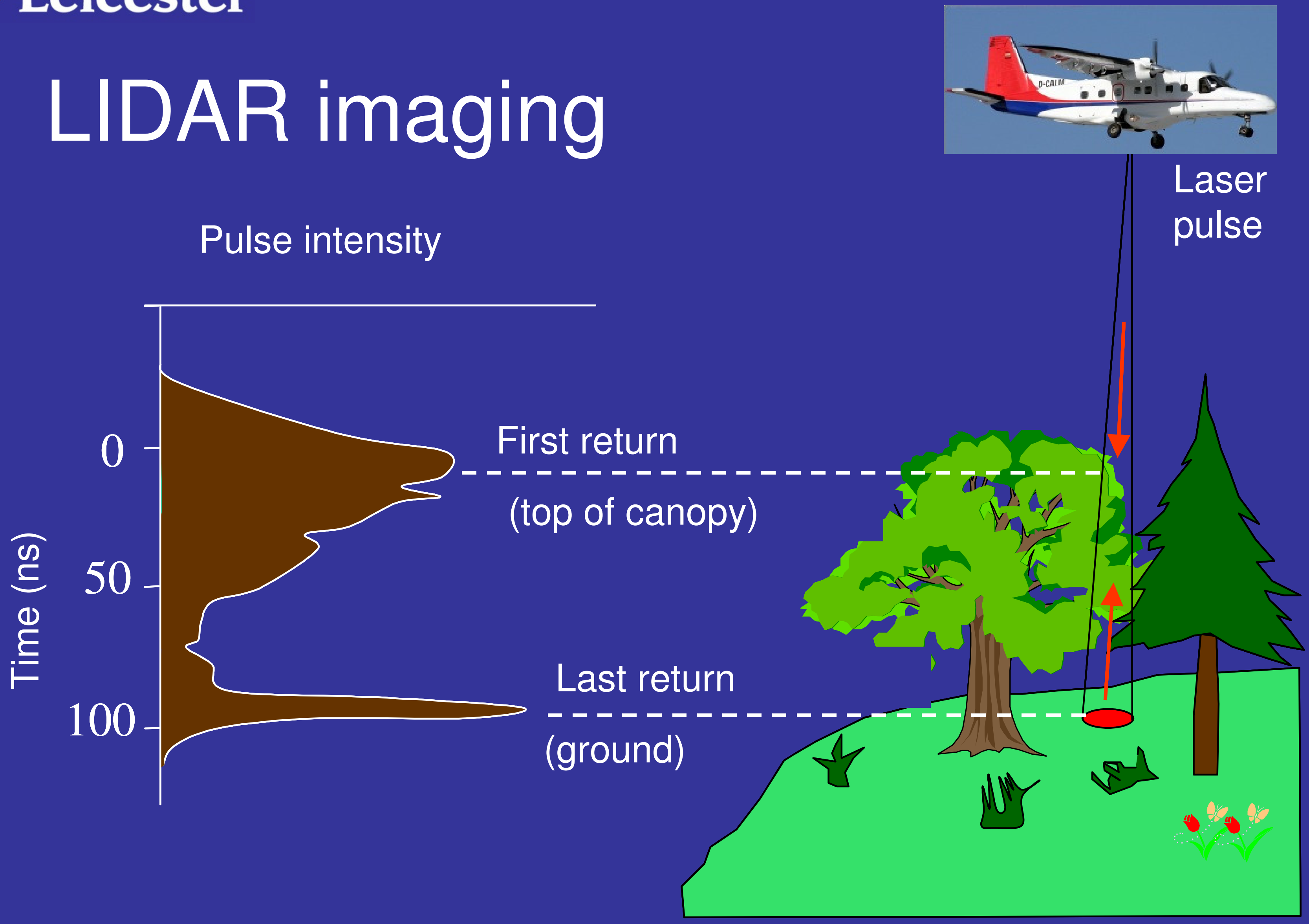
The Leica ALS50 Airborne Laser Scanner is a laser-based system for the acquisition of topographical data for digital surface models and digital images from return signal intensity data.

ARSF deploys a highly-capable Dornier 228-101 research aircraft

- AISA Eagle & Hawk hyperspectral instruments (Specim)
- Leica ALS50-II LiDAR
- Leica RCD105 39 megapixel digital camera

The Optech Airborne Laser Terrain Mapper 3033 (on loan from University of Cambridge)

LIDAR imaging



after Hill *et al.* 2002

Principle of LiDAR

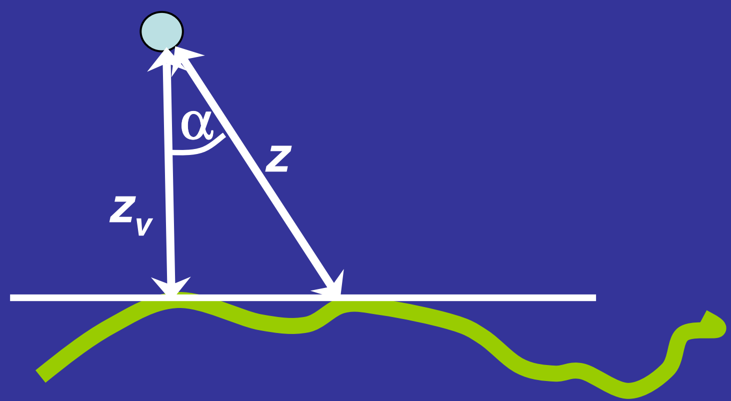
v = speed of light = 299 792 458 m/s or ~ 300,000 km/s

t = two-way travelling time

z = distance of object from sensor

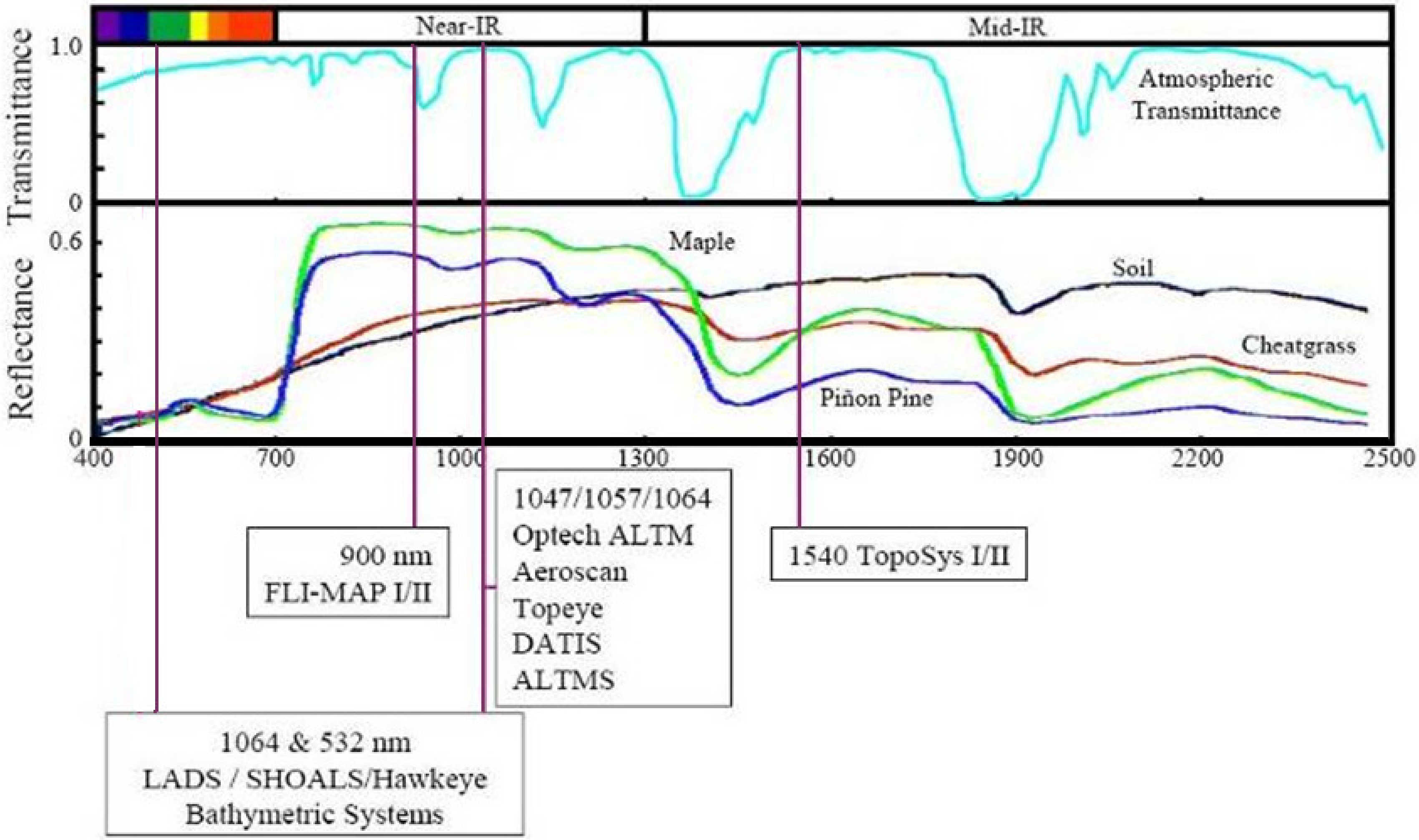
$$z = \frac{t \cdot v}{2}$$

$$z_v = \frac{t \cdot v}{2} \cdot \cos(\alpha)$$



http://www.ferris.edu/faculty/burtchr/papers/lidar_principles.pdf

Wavelengths of LIDAR sensors



Airborne laser scanning

- Active remote sensing technique
- Measuring range/distances
- Data are in the form of a point cloud (x,y,z)

http://www.igi-systems.com/index/pic_index.gif

Why airborne laser scanning?

1. capable of rapidly generating dense, accurate, digital models of the topography and vertical structure of the target surface

2. cost-efficient tool for end users in various application areas

3. for any application with a need for high point density, laser altimetry offers unique technical capabilities, lower field-operation costs and reduced post-processing time and effort compared to traditional survey methods

Flood (2001)

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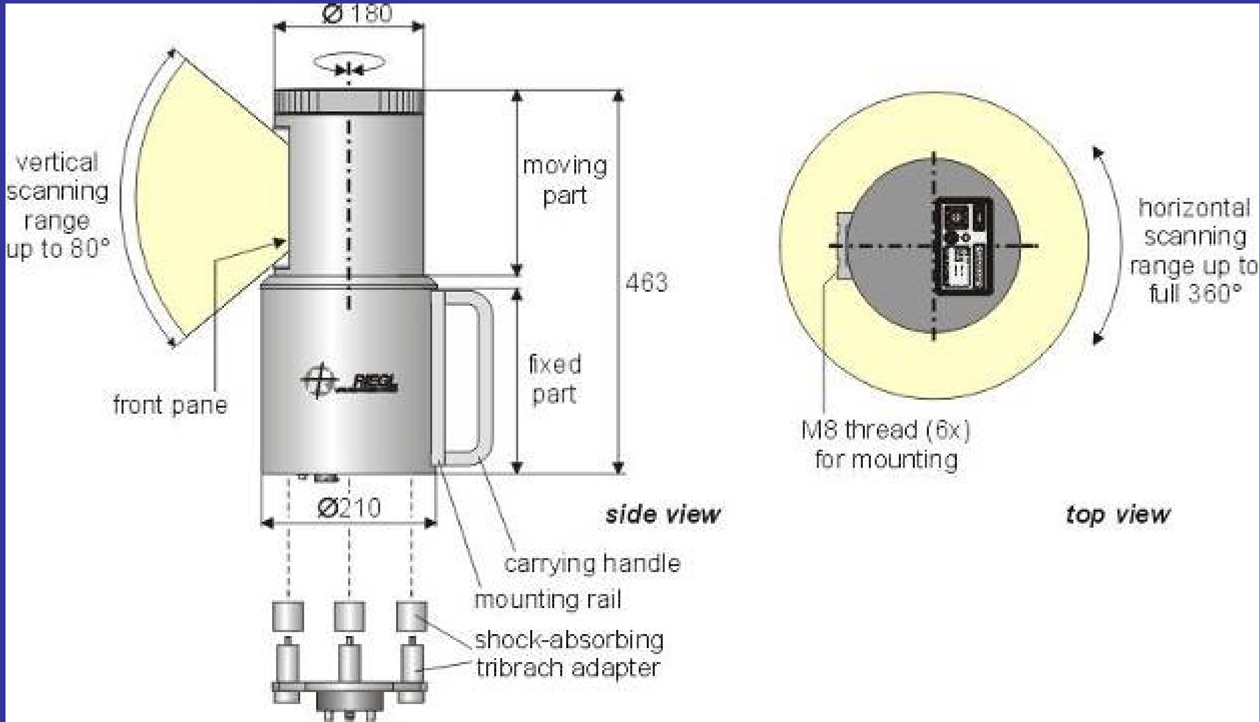
Terrestrial LIDAR

- Static & mobile
- Versatile non-intrusive survey
- Real-time data acquisition in a variety of industrial & research contexts:
  - 3D urban modelling
  - vehicle navigation/navigation corridor
  - construction site monitoring
  - environmental modelling

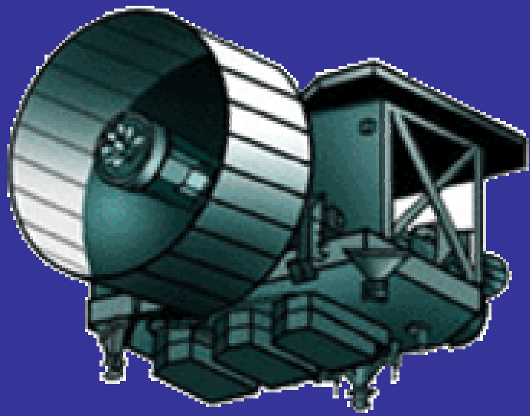
Terrestrial laser scanning

- Surveying
- Mobile mapping
- Small scale deformation
- Vegetation



Spaceborne LIDAR

- Geoscience Laser Altimeter System (GLAS)
- ICESAT satellite platform
- precision surface LIDAR + sensitive dual wavelength cloud and aerosol LIDAR
- infrared and visible laser pulses at 1064 nm and 532 nm wavelengths
- eye-safe signal levels
- GLAS takes data along ground tracks defined by the sequence of laser spots
- GLAS produces a series of approximately 70 m diameter spots (footprints) that are separated by ca. 170 m along track



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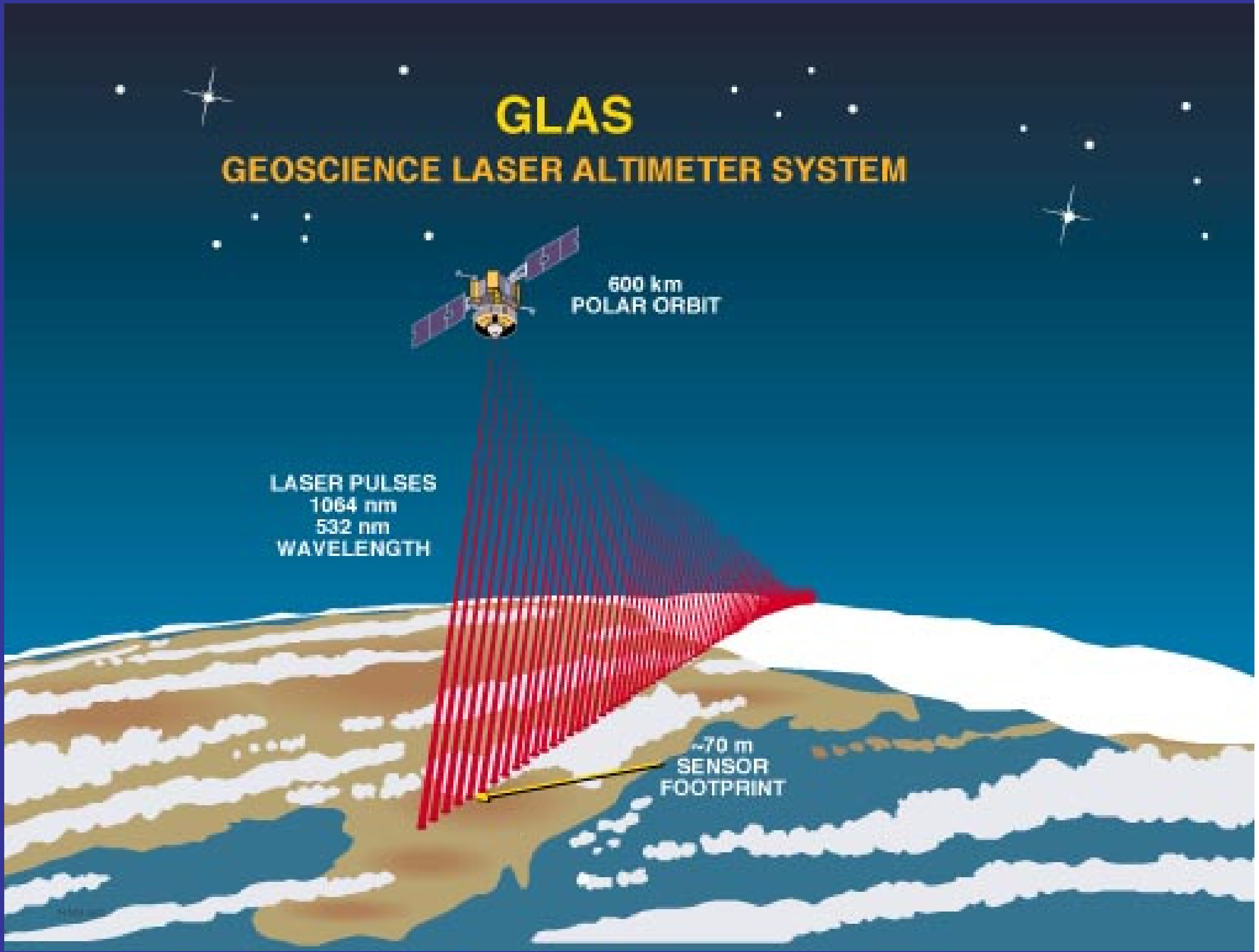
Spaceborne LIDAR: ICESAT-GLAS

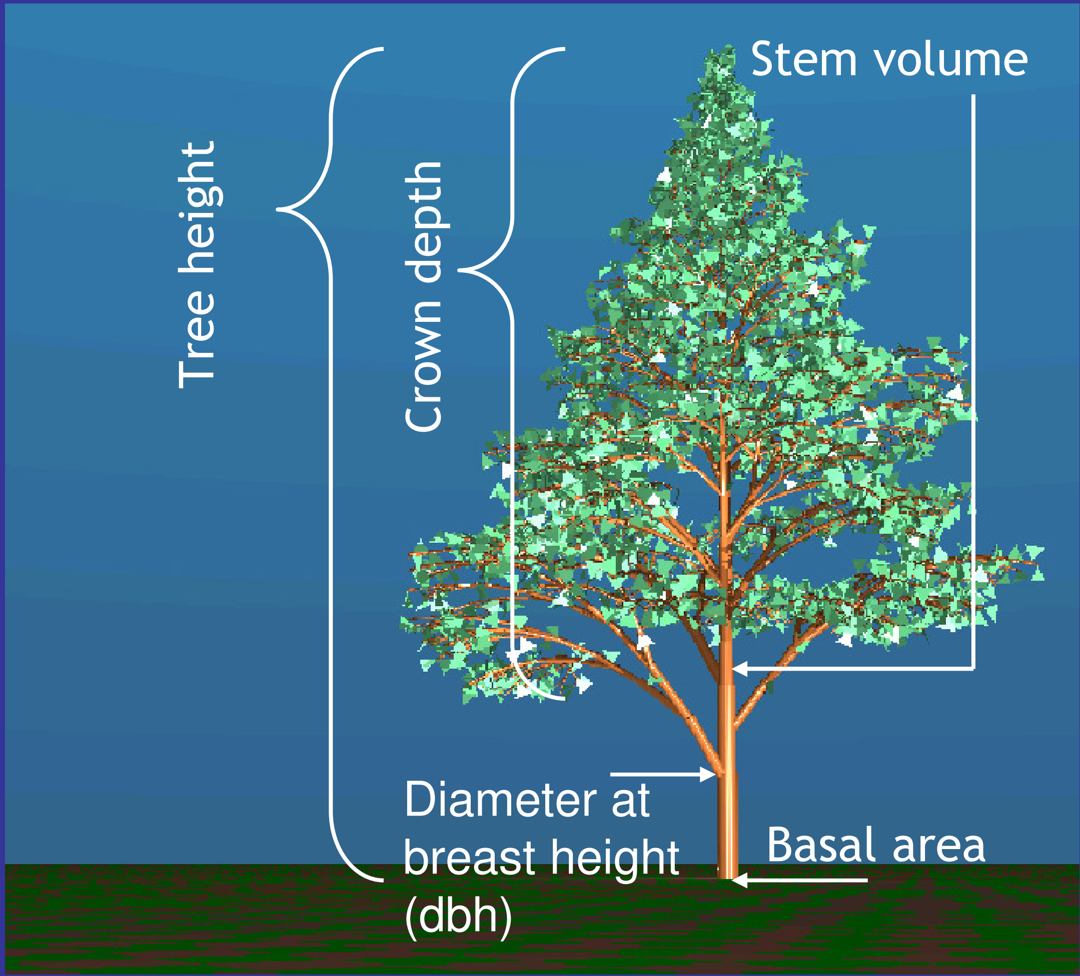
- Nadir-pointed laser altimeter
- Spacecraft enables off-nadir pointing capability
- Measures polar ice-sheets, changes in topography, cloud heights, planetary boundary heights, aerosol vertical structure, and land and water topography
- Launched on 13 January 2003



APPLICATIONS: FOREST MAPPING

Forest structure and biomass

- Trees can be modelled as structures (Lindenmayer system)
- New mapping techniques are sought



3D Forest canopy models

- A forest canopy can be modelled based on Lindenmayer systems

Axiom: a

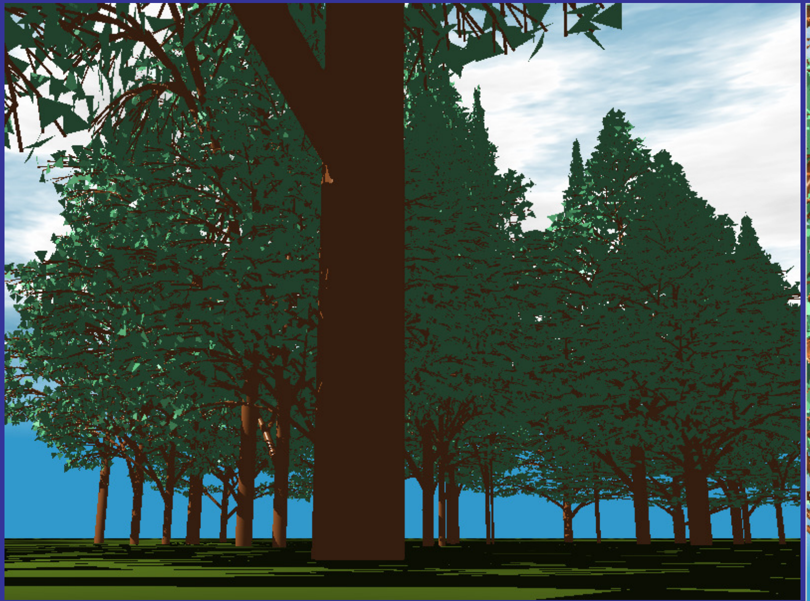
Productions: a → b

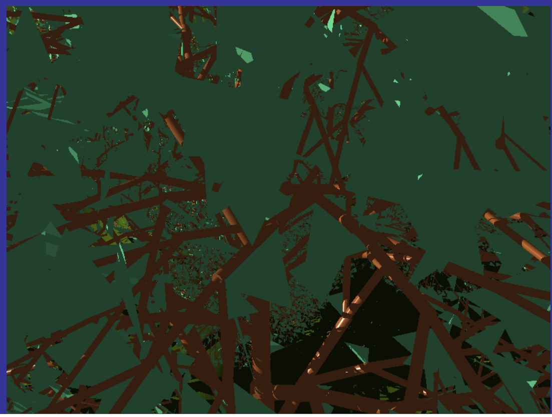
b → ab

a
b
ab
bab
abbab
bababbab
abbababbabbab

- Visualisation with POVRAY (ray tracing model, http://www.povray.org/)

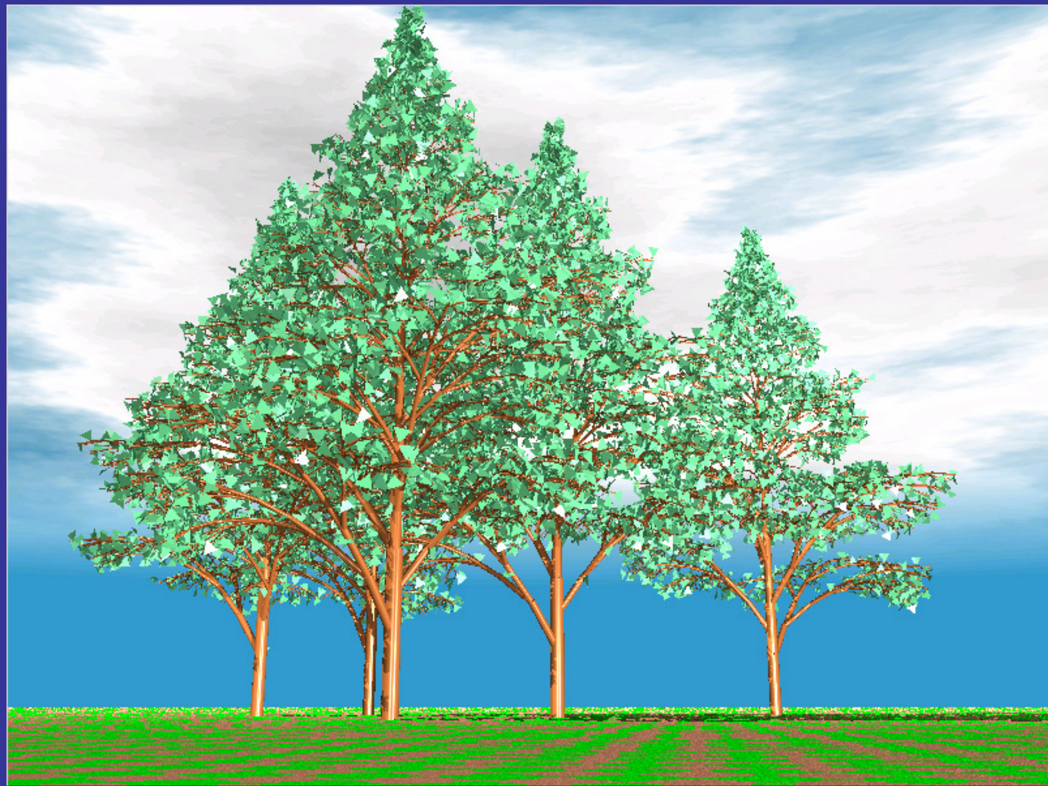
3D Forest canopy models



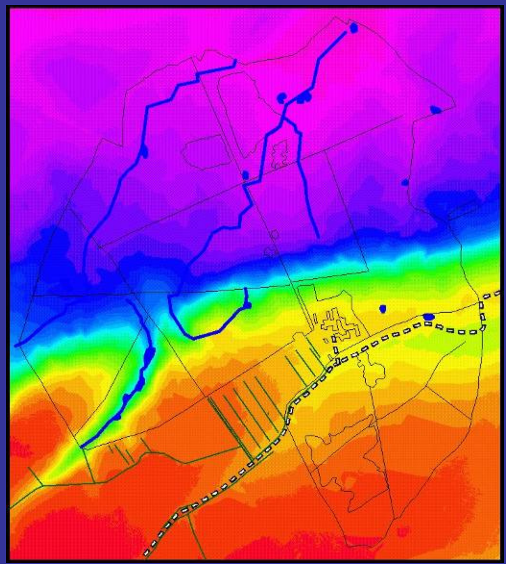


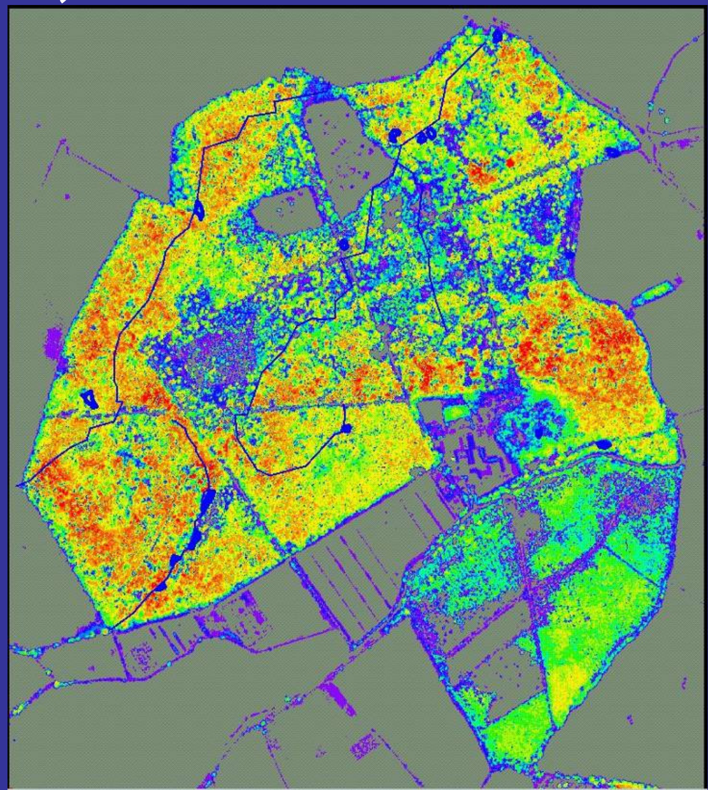
Forest stand characterisation

- Forest canopy height – maximum height
- Top height - total height of the 100 trees of largest diameter at breast height per hectare



Airborne LIDAR: Monks Wood, UK





Digital Surface Model = Digital Terrain Model + Canopy Height Model

Carbon pool estimation using allometry

- Estimate stem volume from top height:

$$V_{\text{stem}} = \frac{6.357834}{0.59822} \exp(0.174045 \cdot h_{\text{top}})$$

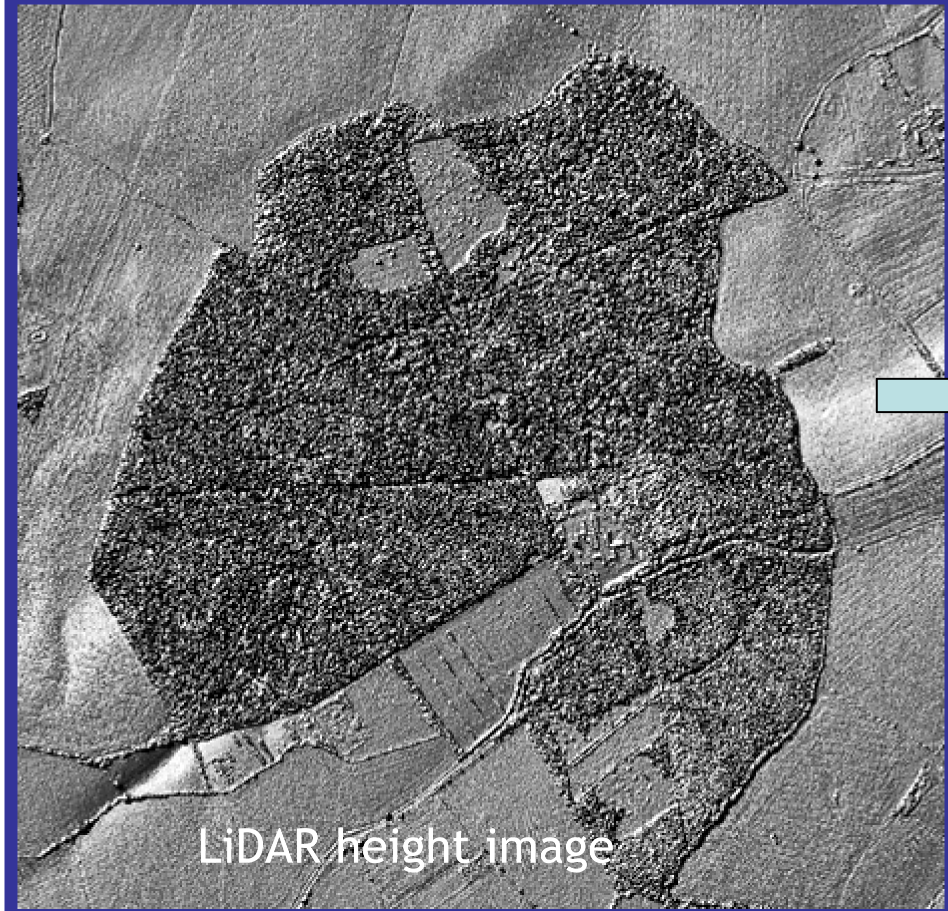
- Estimate carbon content using a biomass expansion factor, a dry mass conversion factor and a carbon content conversion factor:

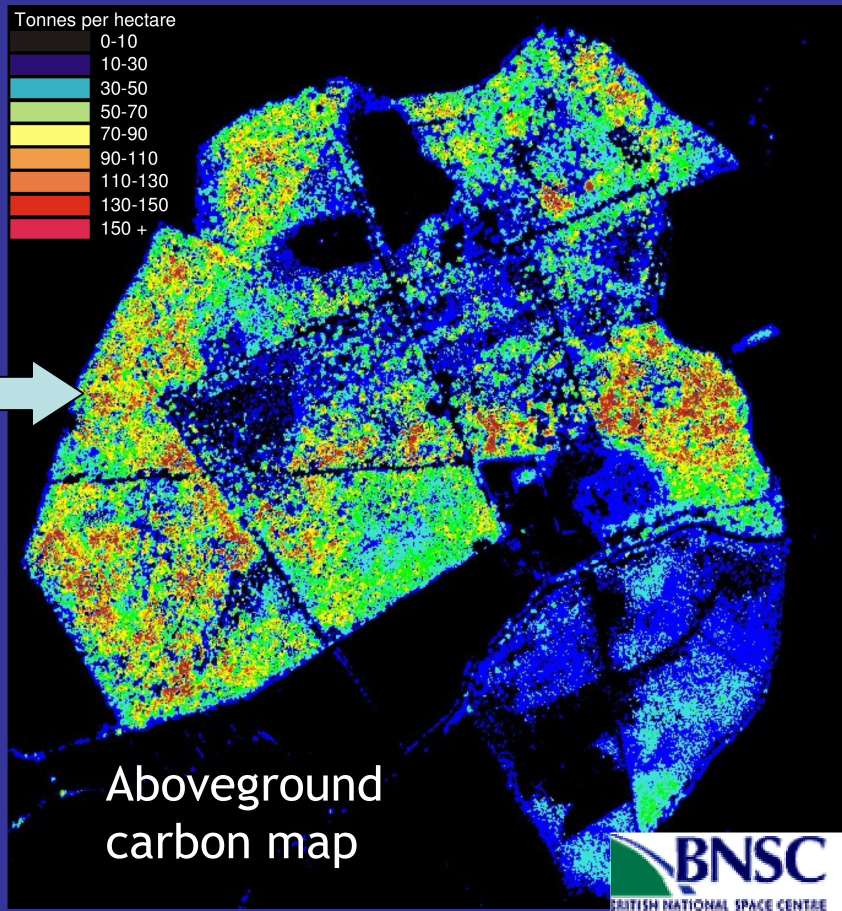
$$CC = V_{stem} \cdot 1.36 \cdot 0.55 \cdot 0.49$$

- Estimate carbon content of the understorey based on empirical relationship if trees > 15 m.

$$C_{\text{underst}} = C_{\text{overst}} \cdot (59.133 \cdot C_{\text{overst}}^{-1.2977})$$

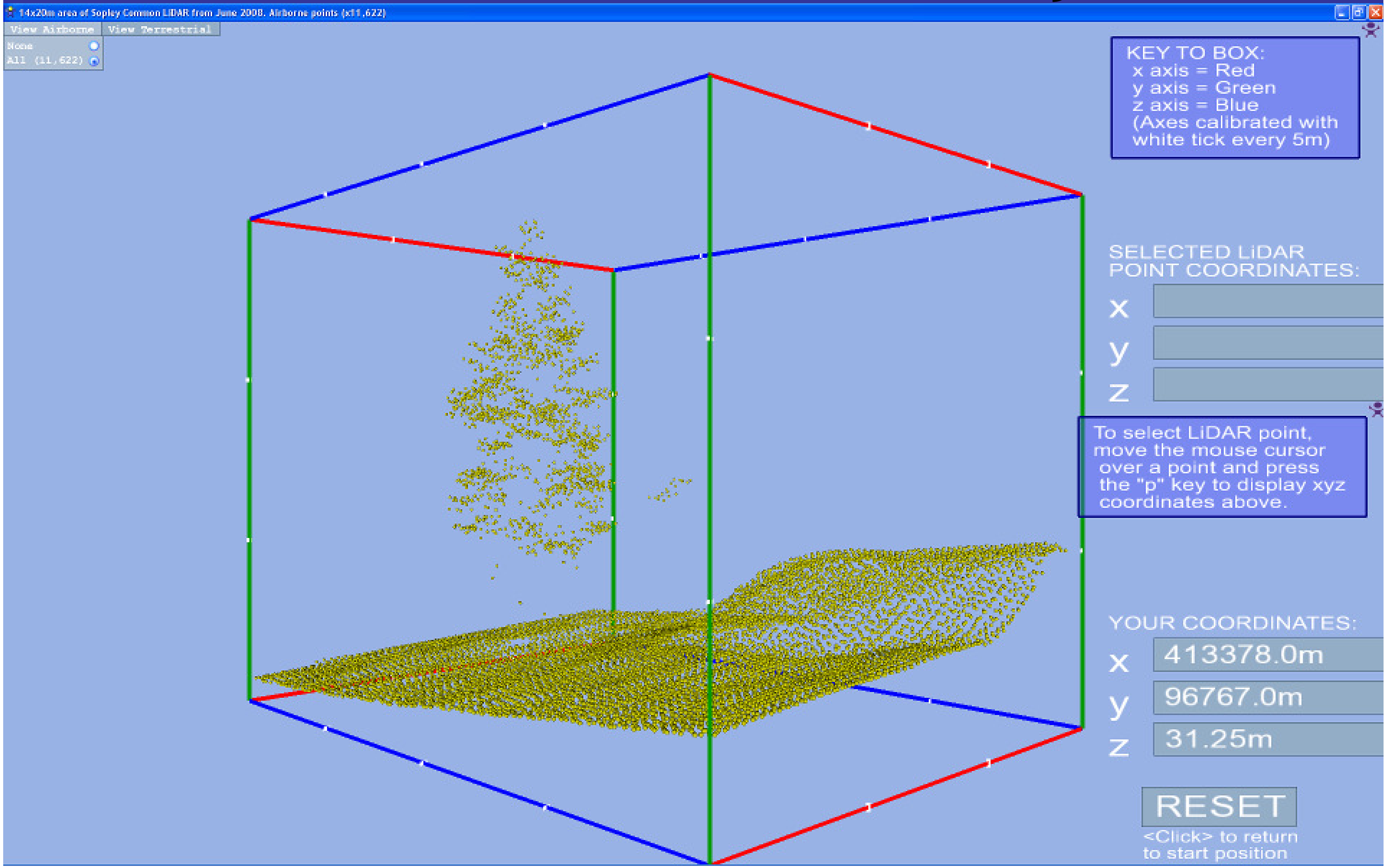
Carbon accounting of Monks Wood, UK, using LIDAR



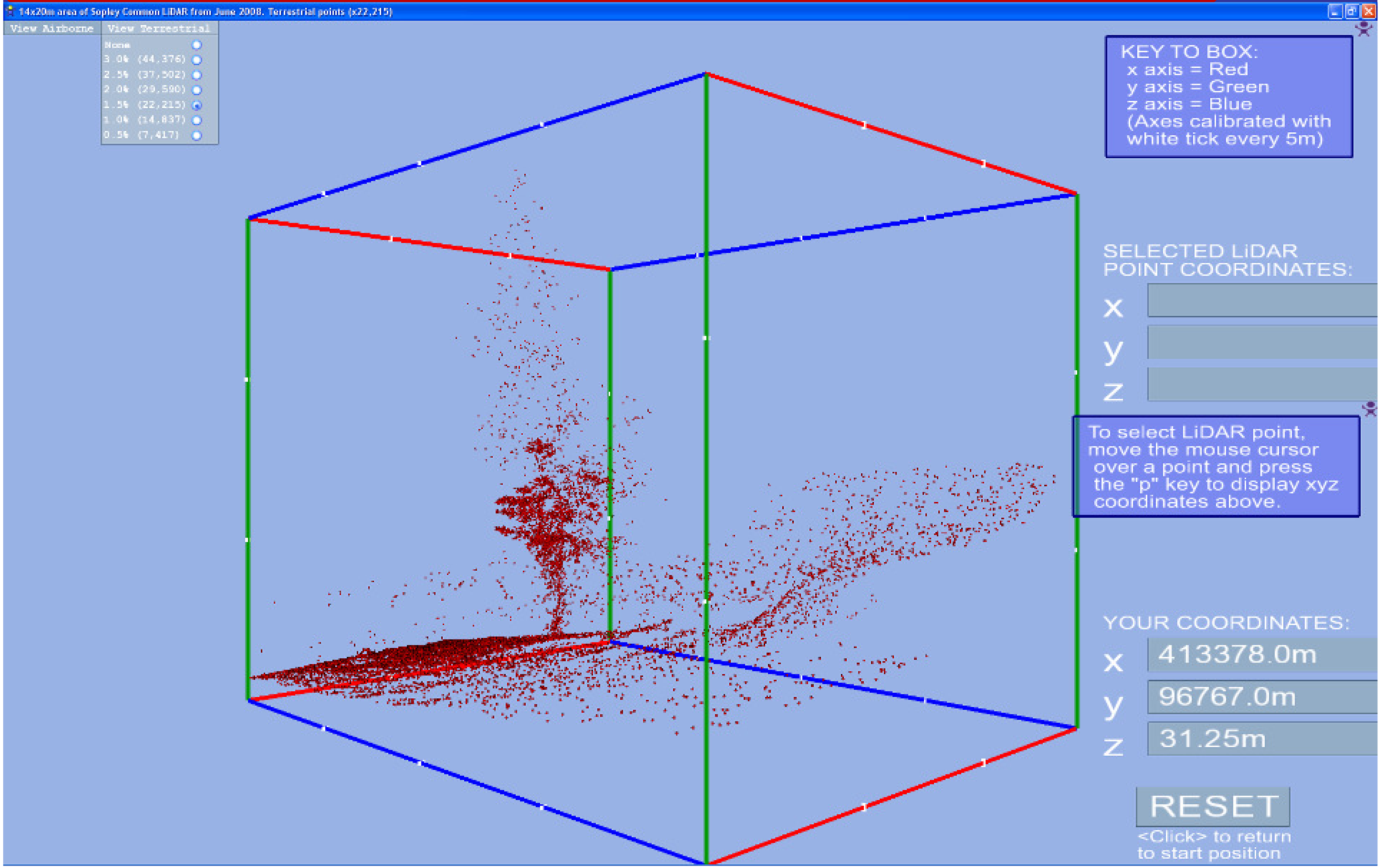


Patenaude et al. (2002), *ForestSAT 2002 Edinburgh*.

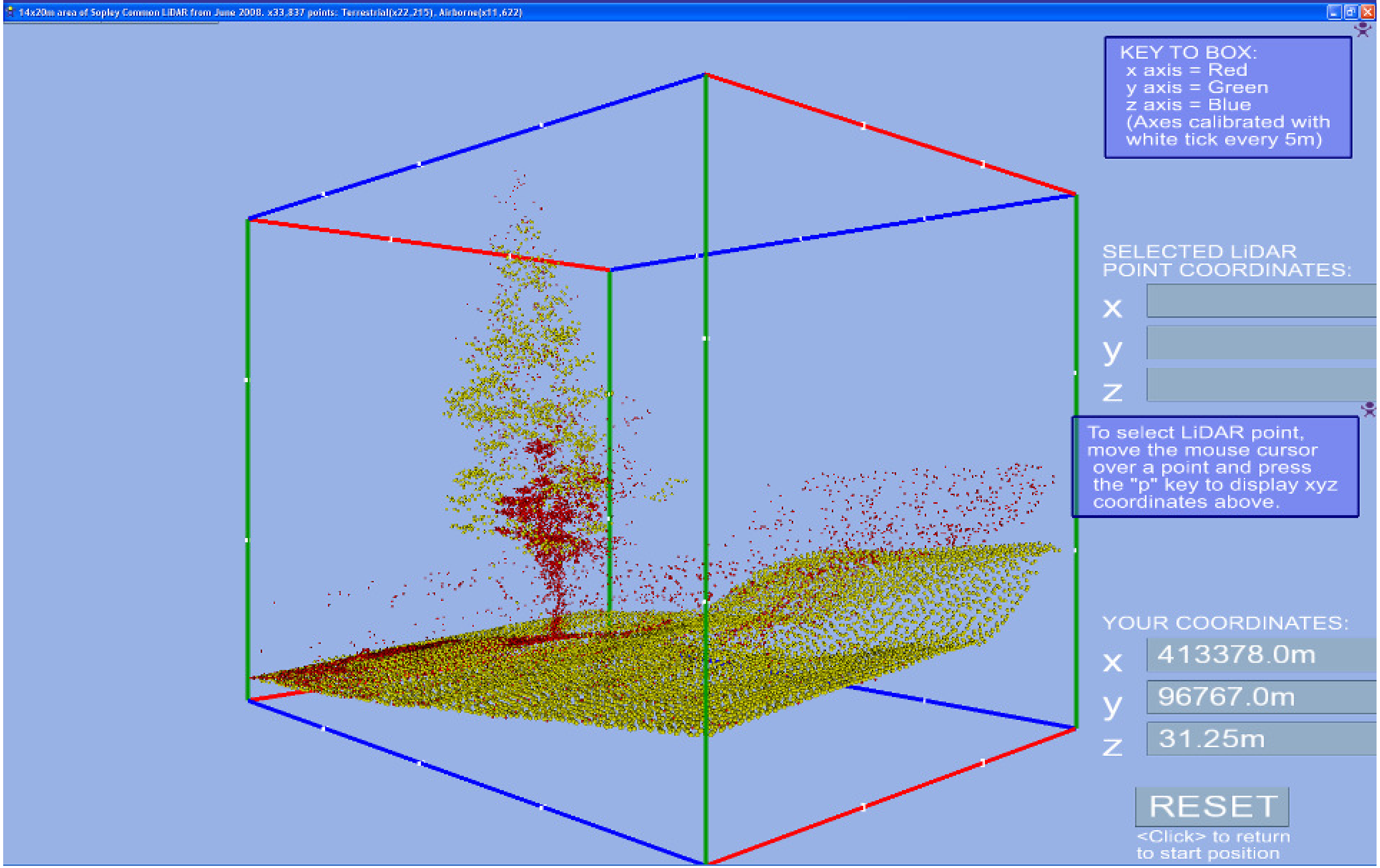
Airborne LiDAR in Virtual Reality



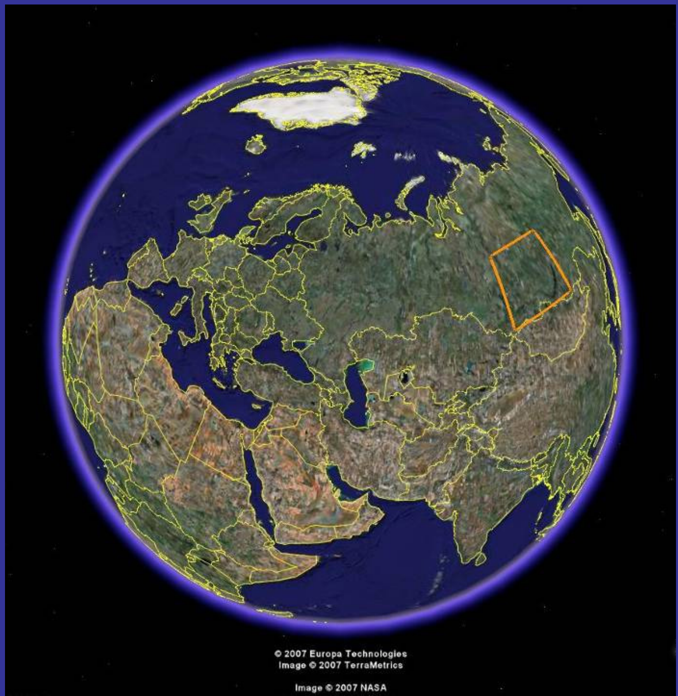
Terrestrial LiDAR in Virtual Reality

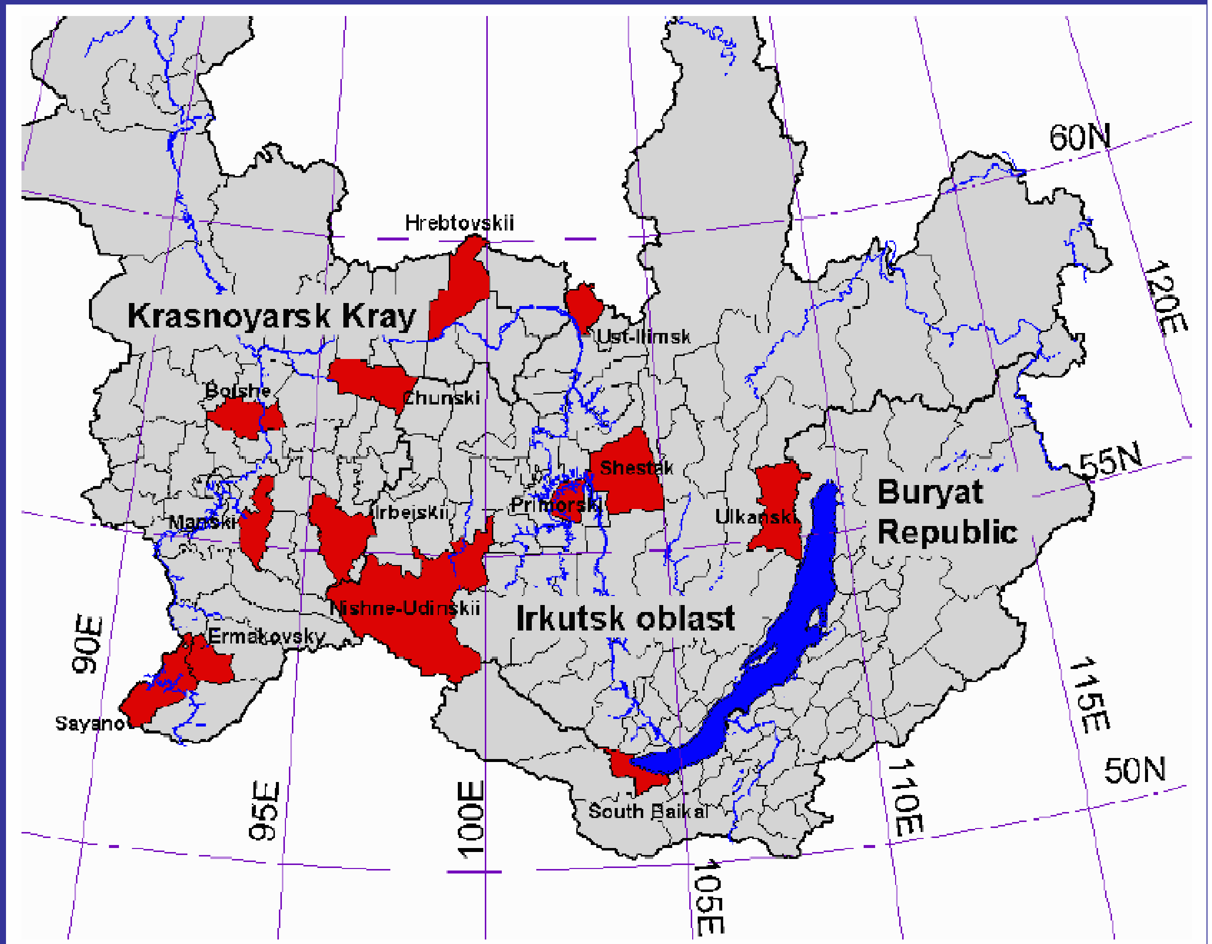


Integrated LiDAR in Virtual Reality



ICESAT-GLAS over Siberia



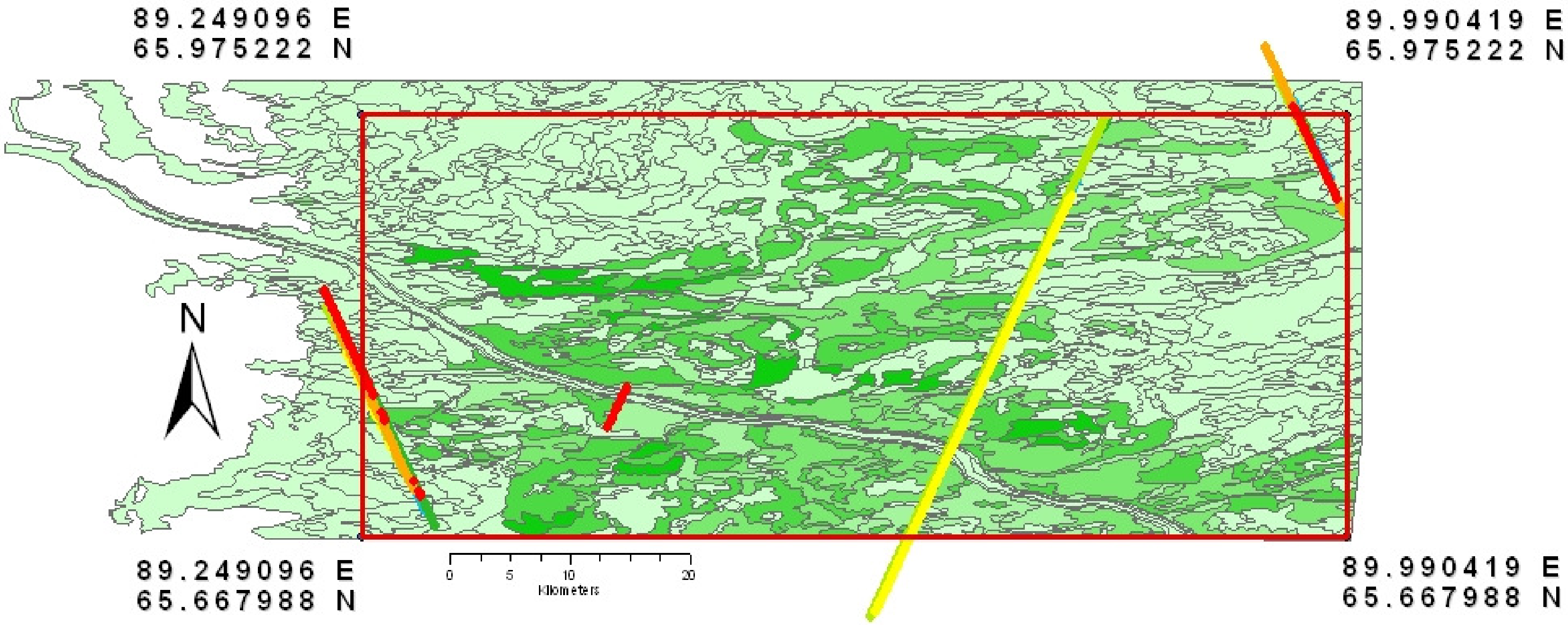


ICESAT-GLAS over Siberia

Siberian forest

- Low and high biomass forest stands

Location of ICESat/GLAS footprints acquired over Nizhnjaja Tunguska, Siberia, within a subset area of high tree coverage (in volume, m³/ha)



Nizhnjaja_Tunguska_SUBSET

VOLUME of trees in m³/ha

- 0 - 32
- 33 - 63
- 64 - 95
- 96 - 126
- 127 - 158

Boundary of ICESat/GLAS subset area

Eastings & Northings of 4 corners were used to order subset of data from NASA at nsidc.org/forms /glas_subset_form.html

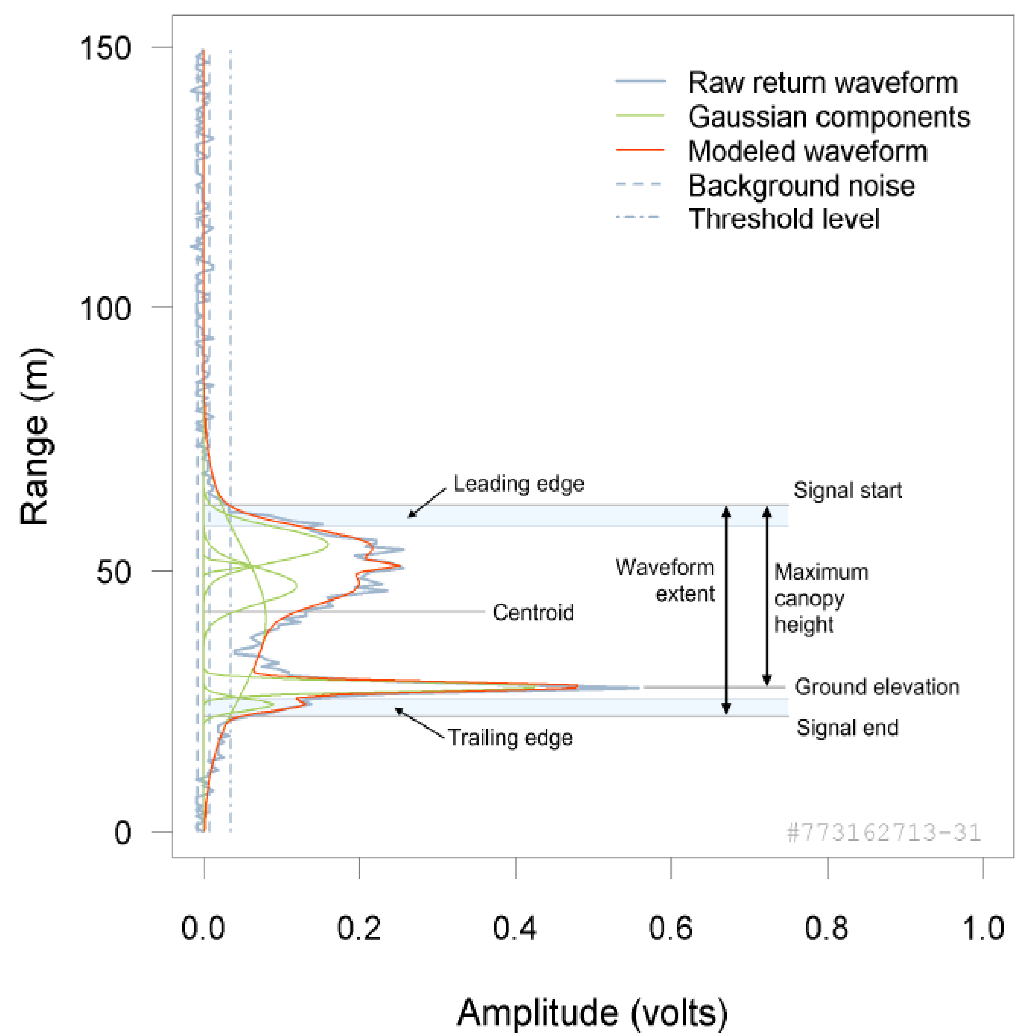
Satellite Laser Footprints

- coords_03100413_x116.csv
- coords_04021721_x159.csv
- coords_04100321_x249.csv
- coords_05021715_x360.csv
- coords_05052016_x183.csv
- coords_06022220_x311.csv

where... coords_<number> denotes YYMMDDHH of first data acquisition within that file.

and... x<number>.csv denotes number of footprints in each file. 1378 footprints in total.

ICESAT-GLAS waveform characterisation



Bimodal GLAS waveform over forest land with small topographic slope (Brenner et al., 2003).

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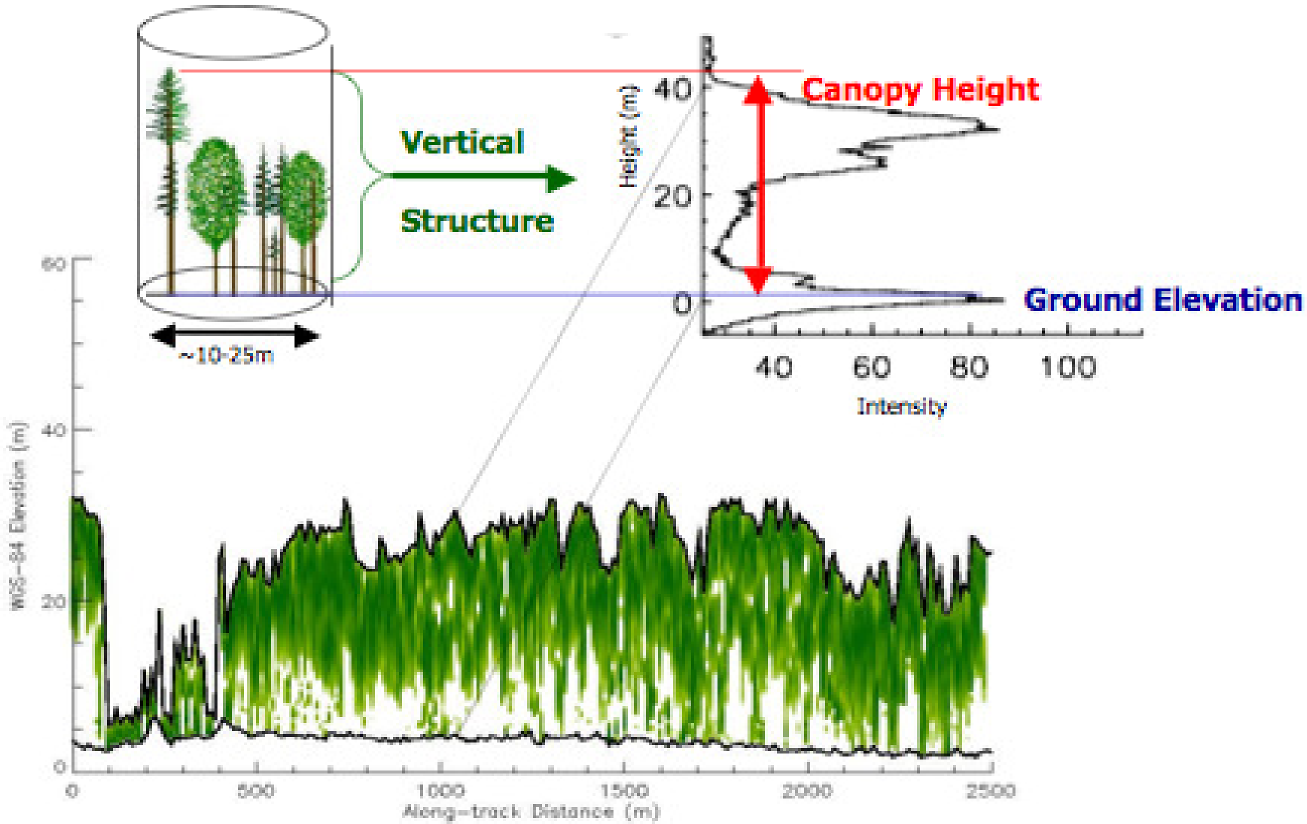
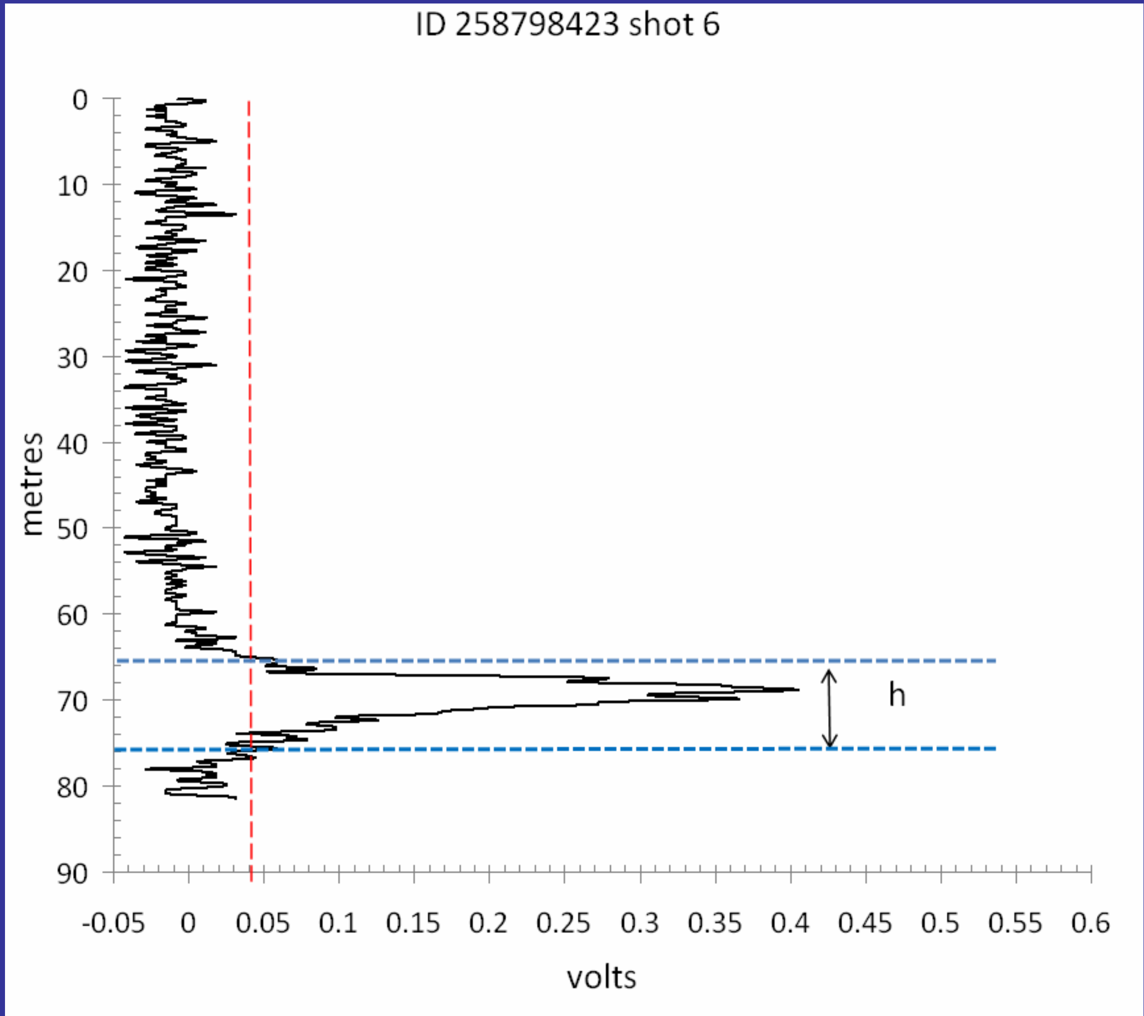
Canopy height: Distance first-last mode

(Drake *et al*, 2002 ; Dubayah and Drake, 2000)



ICESAT-GLAS over Siberia

Forest height from ICESAT-GLAS

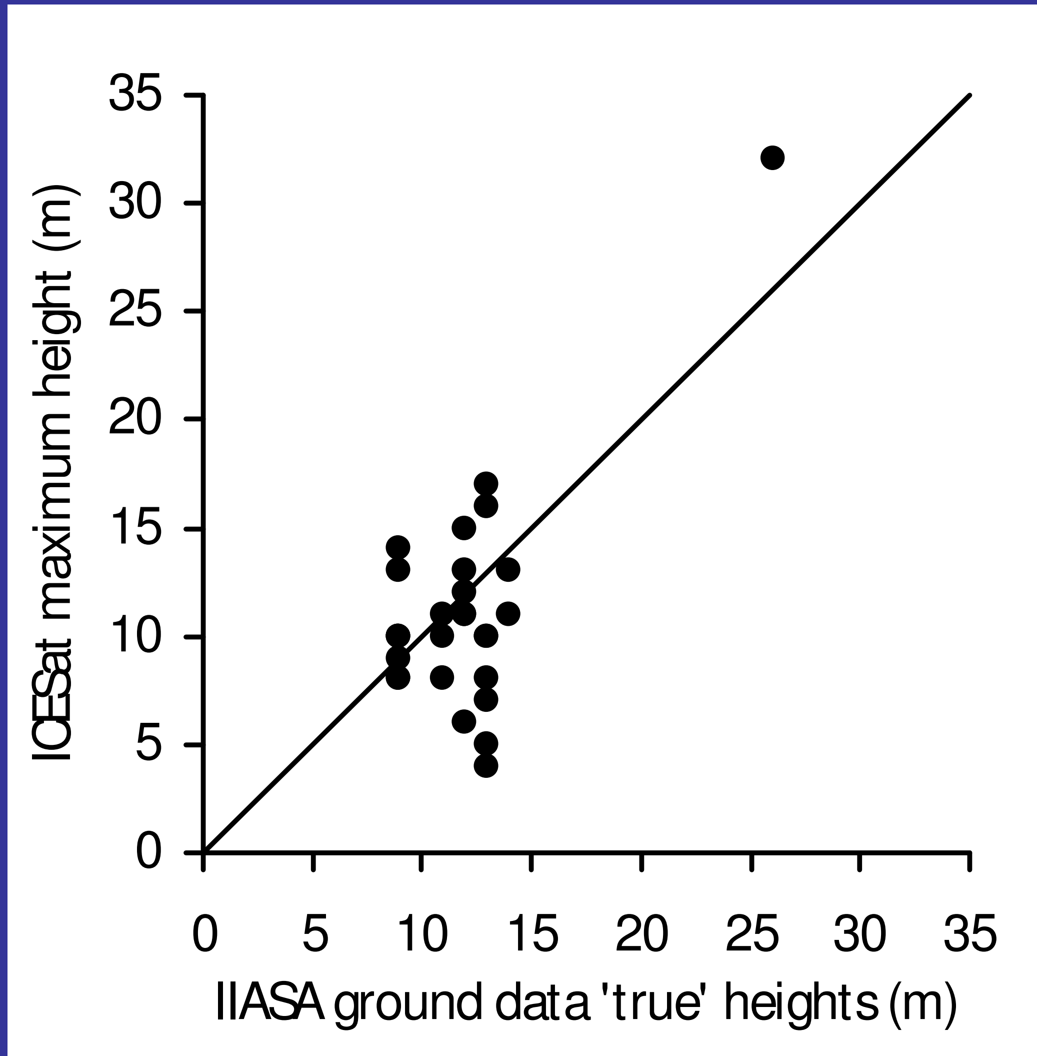


ICESAT-GLAS over Siberia

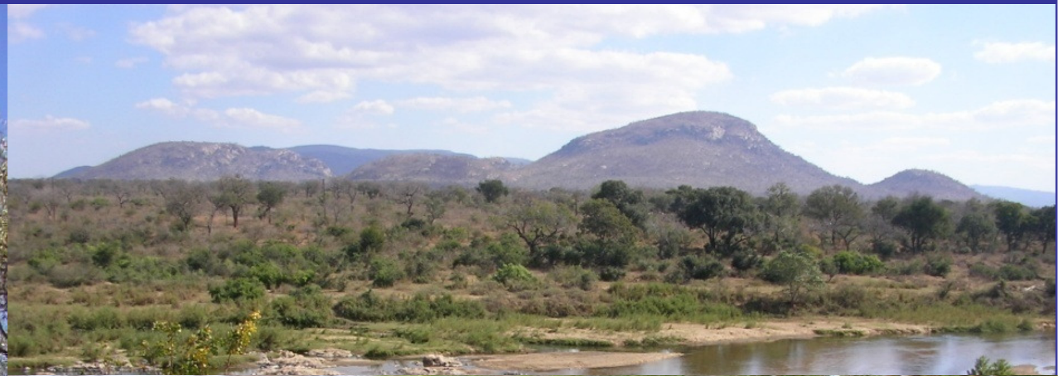
Validation

3 outliers removed

rmse = 3.77 m

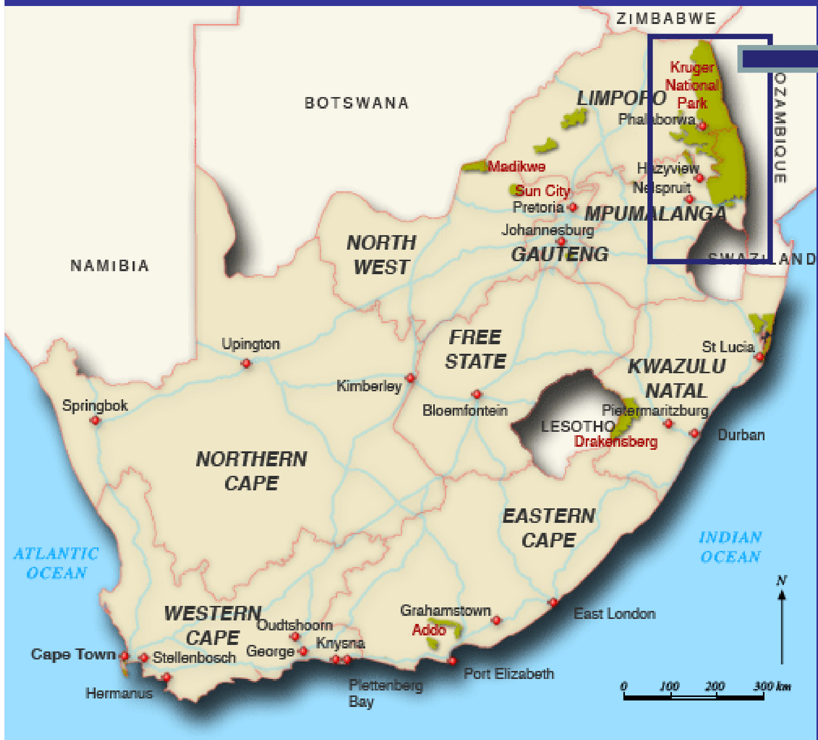


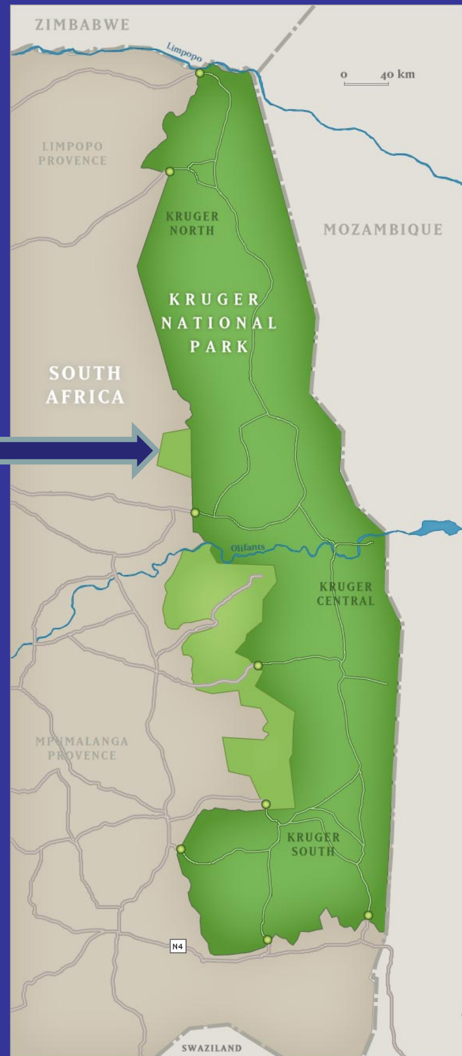
ICESAT-GLAS over the Kruger National Park, South Africa



ICESAT-GLAS over the Kruger National Park, South Africa

- **Study area**
- Kruger National Park is located in South Africa
- It covers nearly 2 million hectares
- Presents a good test site because of the diversity of its ecosystems.





http://www.sanparks.org/

ICESAT-GLAS over the Kruger National Park, South Africa

Data coverage

GLAS _ Feb2003

GLAS _Feb2004

GLAS _May2004

GLAS _Mar 2006

GLAS _Mar 2007

GLAS _Oct2007

GLAS _ Feb2008

ICESAT-GLAS over the Kruger National Park, South Africa

- Data has been ordered from http://nsidc.org/data/icesat/order.html

- Among the 15 data products: GLA01,GLA02,….GLAS15, two products have been used in this research:

- **GLA01** contains the altimeter waveforms for each laser shot
- **GLA14** contains the altimetry data with land surface elevations, including the laser footprint reflectance and geolocation

- These datasets were acquired for 2008-02-19 to 2008-03-15 during the temporal coverage of laser L3J.
- There are 6 tracks with 8519 waveforms in total and 2629 waveforms are located within the study area.

ICESAT-GLAS over the Kruger National Park, South Africa

- **Data analysis tools**

- **NGAT Tool** : downloaded from http://nsidc.org/data/icesat/tools.html
- This tool uses the GLA14 altimetry product to derive for each shot`s unique number, date and time and acquisition, latitude and longitude (in decimal degrees), elevation (meters) and geoid (Ranson *et al.*, 2004)
- **IDLreadGLAS Tool**: downloaded http://nsidc.org/data/icesat/tools.html
- This tool was used to process and explore the waveforms and to identify and extract parameters of interest. Raw data that was ordered from NASA were generated to produce usable data, including unique number, shot number, shot time, number of samples and uncompressed waveform values in volts (Sidel, 2005)
- **R:** statistical programming language to process and explore the full waveforms

ICESAT-GLAS over the Kruger National Park, South Africa

NGAT output: GLA14

Record Number	Time	Date	Latitude	Longitude	Elevation	geoid
1620109274	02/19/2008	03:02:07.464	-22.049320	31.296953	1538.479	10.593590
1620109274	02/19/2008	03:02:07.489	-22.050868	31.296724	1543.244	10.595385
1620109274	02/19/2008	03:02:07.514	-22.052415	31.296496	1562.778	10.597179
1620109274	02/19/2008	03:02:07.564	-22.055513	31.296042	1572.799	10.600769
1620109274	02/19/2008	03:02:07.614	-22.058620	31.295591	1614.681	10.604359
1620109274	02/19/2008	03:02:07.639	-22.060175	31.295367	1676.158	10.606154
1620109274	02/19/2008	03:02:07.664	-22.061733	31.295143	1671.681	10.607949
1620109274	02/19/2008	03:02:07.689	-22.063296	31.294917	1523.506	10.609744
1620109274	02/19/2008	03:02:07.714	-22.064848	31.294694	1584.276	10.611538
1620109274	02/19/2008	03:02:07.764	-22.067955	31.294246	1578.468	10.615128
1620109274	02/19/2008	03:02:07.789	-22.069505	31.294022	1617.651	10.616923
1620109274	02/19/2008	03:02:07.814	-22.071053	31.293796	1633.187	10.618718
1620109274	02/19/2008	03:02:07.839	-22.072604	31.293569	1605.256	10.620513
1620109274	02/19/2008	03:02:07.864	-22.074154	31.293341	1571.143	10.622308
1620109274	02/19/2008	03:02:07.889	-22.075706	31.293111	1539.225	10.624103
1620109274	02/19/2008	03:02:07.914	-22.077257	31.292879	1537.936	10.625897

ICESAT-GLAS over the Kruger National Park, South Africa

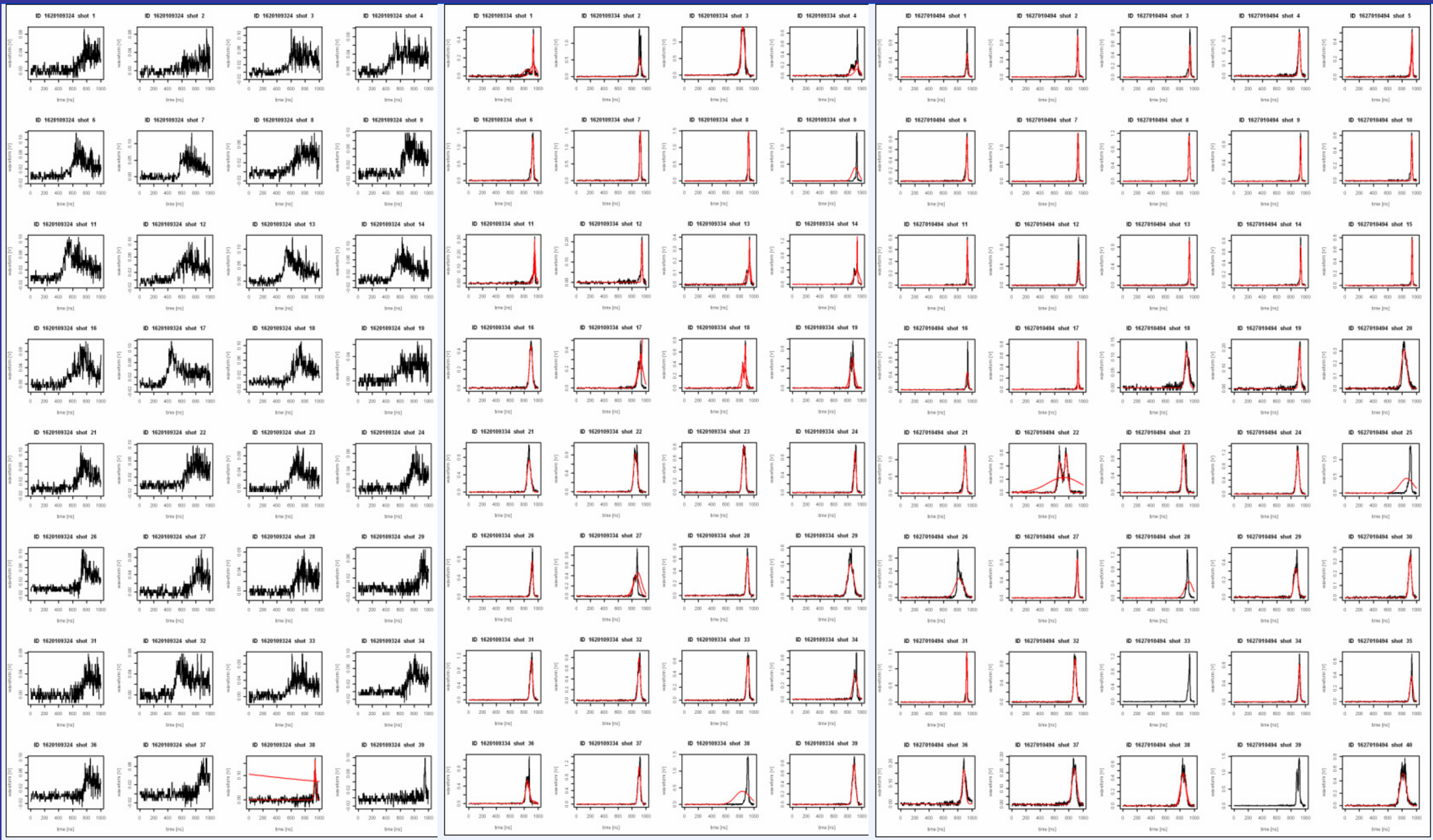
IDLreadGLAS: GLA01

Uncompressed waveform values in volts

Record Number	Shot Time	N of Samples	Shot N														
1620109274	256662127.4	1000	1														
-0.008379	-0.008379	-0.008379	-0.008379	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	0.011646	0.011646	0.011646	0.011646	0.004971	0.004971
1620109274	256662127.4	1000	2														
-0.008379	-0.008379	-0.008379	-0.008379	-0.0017	-0.0017	-0.0017	-0.0017	0.004971	0.004971	0.004971	0.004971	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017
1620109274	256662127.5	1000	3														
-0.008379	-0.008379	-0.008379	-0.008379	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	0.004971	0.004971	0.004971	0.004971	-0.0017	-0.0017
1620109274	256662127.5	1000	4														
-0.008379	-0.008379	-0.008379	-0.008379	-0.0017	-0.0017	-0.0017	-0.0017	-0.01505	-0.01505	-0.01505	-0.01505	-0.00838	-0.00838	-0.00838	-0.00838	-0.0017	-0.0017
1620109274	256662127.5	1000	5														
-0.008379	-0.008379	-0.008379	-0.008379	-0.00838	-0.00838	-0.00838	-0.00838	0.004971	0.004971	0.004971	0.004971	0.011646	0.011646	0.011646	0.011646	0.004971	0.004971
1620109274	256662127.5	1000	6														
-0.001704	-0.001704	-0.001704	-0.001704	-0.0017	-0.0017	-0.0017	-0.0017	-0.00838	-0.00838	-0.00838	-0.00838	0.004971	0.004971	0.004971	0.004971	-0.00838	-0.00838
1620109274	256662127.6	1000	7														
-0.001704	-0.001704	-0.001704	-0.001704	0.004971	0.004971	0.004971	0.004971	-0.0017	-0.0017	-0.0017	-0.0017	0.004971	0.004971	0.004971	0.004971	-0.0017	-0.0017
1620109274	256662127.6	1000	8														
-0.008379	-0.008379	-0.008379	-0.008379	-0.00838	-0.00838	-0.00838	-0.00838	-0.00838	-0.00838	-0.00838	-0.00838	0.004971	0.004971	0.004971	0.004971	0.004971	0.004971
1620109274	256662127.6	1000	9														
-0.008379	-0.008379	-0.008379	-0.008379	0.004971	0.004971	0.004971	0.004971	-0.00838	-0.00838	-0.00838	-0.00838	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017
1620109274	256662127.6	1000	10														
0.004971	0.004971	0.004971	0.004971	0.004971	0.004971	0.004971	0.004971	-0.0017	-0.0017	-0.0017	-0.0017	-0.00838	-0.00838	-0.00838	-0.00838	-0.0017	-0.0017
1620109274	256662127.7	1000	11														
0.004971	0.004971	0.004971	0.004971	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	0.004971	0.004971	0.004971	0.004971	-0.00838	-0.00838
1620109274	256662127.7	1000	12														
-0.001704	-0.001704	-0.001704	-0.001704	0.004971	0.004971	0.004971	0.004971	0.004971	0.004971	0.004971	0.004971	0.011646	0.011646	0.011646	0.011646	-0.0017	-0.0017
1620109274	256662127.7	1000	13														
0.011646	0.011646	0.011646	0.011646	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	0.004971	0.004971	0.004971	0.004971	0.011646	0.011646
1620109274	256662127.7	1000	14														
0.011646	0.011646	0.011646	0.011646	0.004971	0.004971	0.004971	0.004971	-0.00838	-0.00838	-0.00838	-0.00838	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017	-0.0017
1620109274	256662127.8	1000	15														
0.004971	0.004971	0.004971	0.004971	-0.00838	-0.00838	-0.00838	-0.00838	0.004971	0.004971	0.004971	0.004971	-0.0017	-0.0017	-0.0017	-0.0017	0.004971	0.004971
1620109274	256662127.8	1000	16														
0.004971	0.004971	0.004971	0.004971	-0.01505	-0.01505	-0.01505	-0.01505	-0.0017	-0.0017	-0.0017	-0.0017	-0.00838	-0.00838	-0.00838	-0.00838	-0.00838	-0.00838

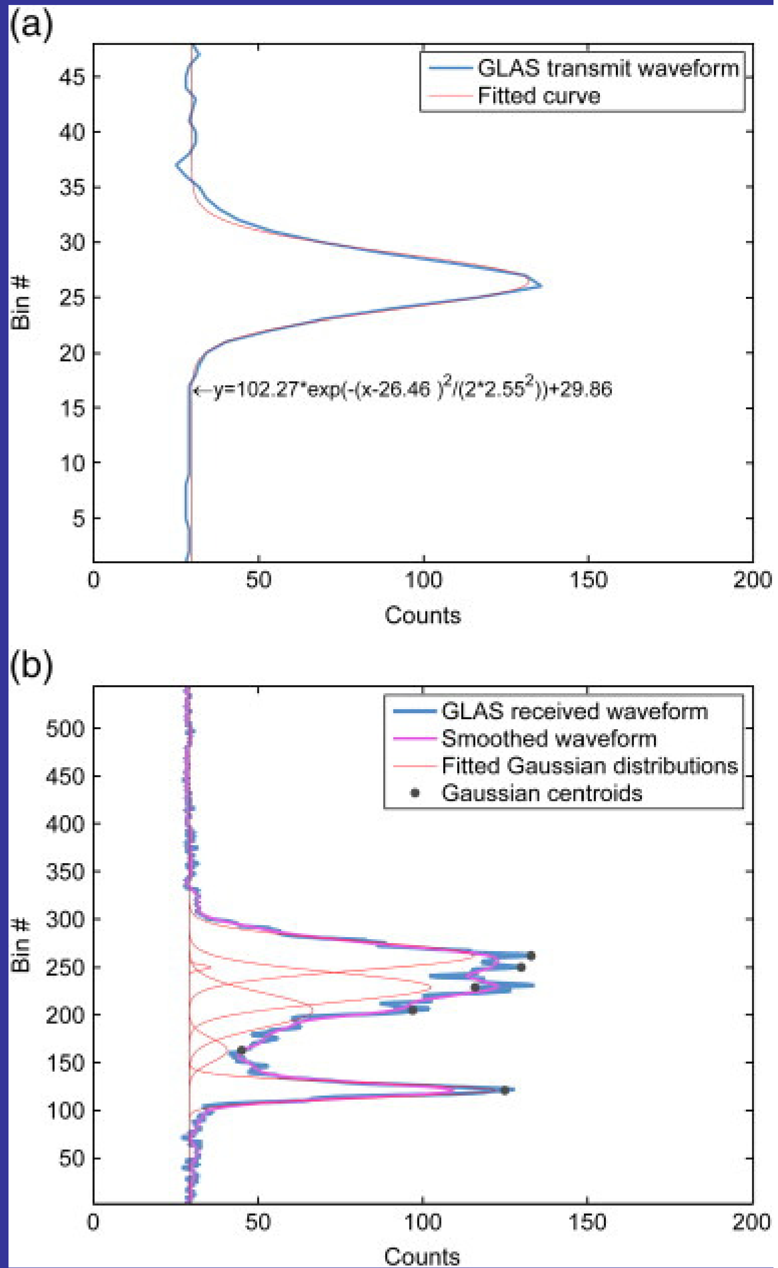
ICESAT-GLAS over the Kruger National Park, South Africa

Waveform modeling in R



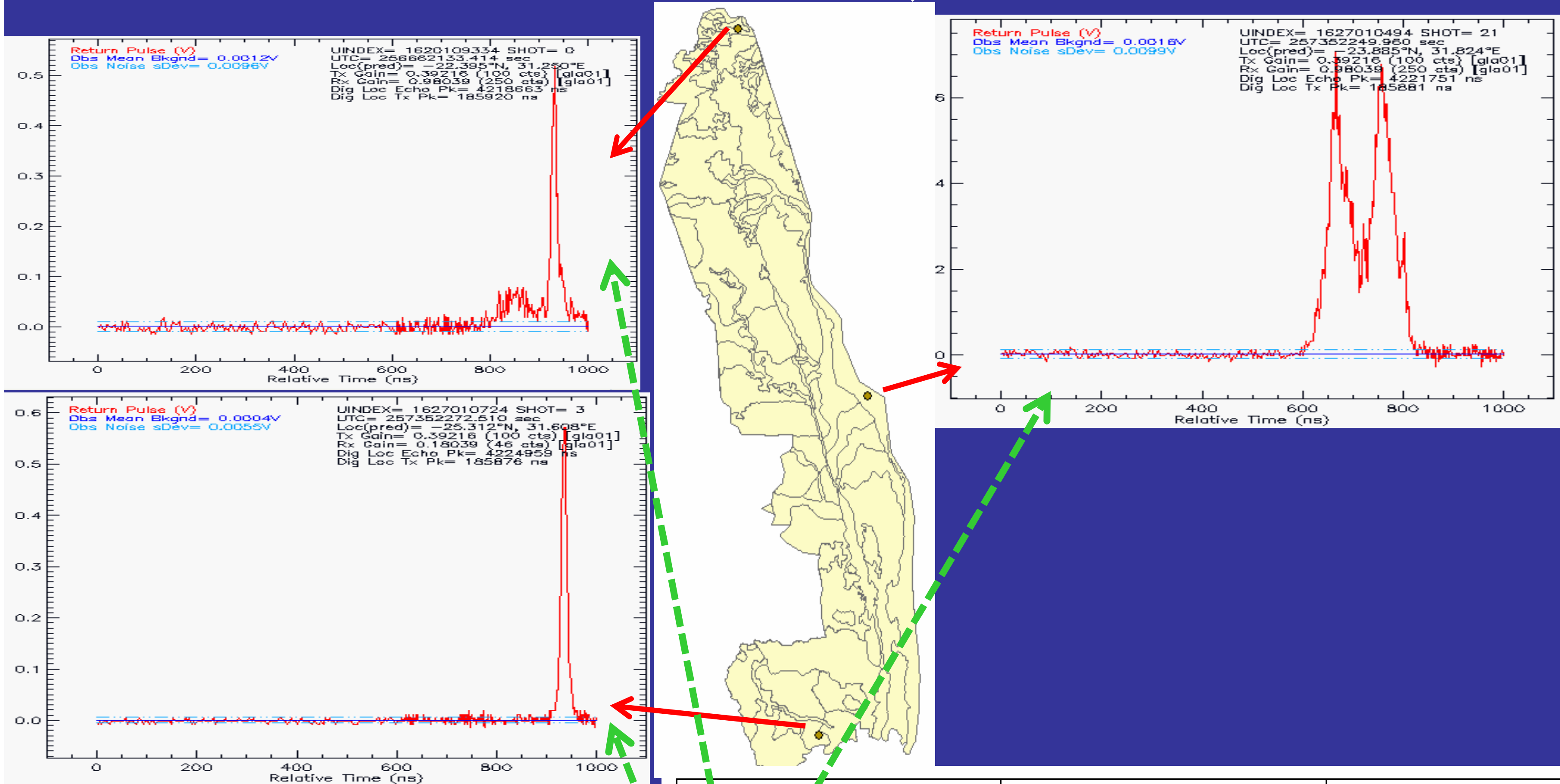
Waveform fitting

- A mixture of Gaussian functions is fitted to the waveform to determine the locations of peaks in the signal.



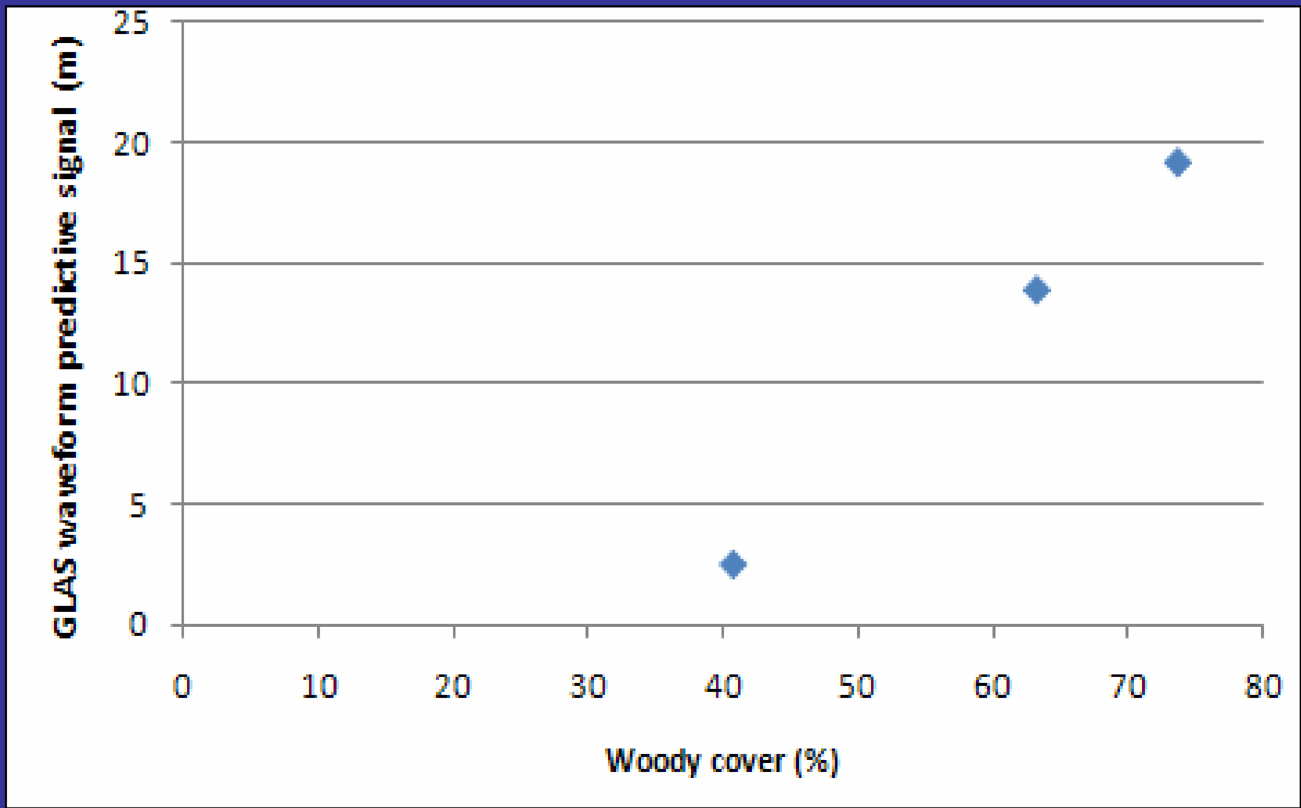
Reproduced from Chen, Q. (2010): Remote Sensing of Environment 114,1610-1627.

ICESAT-GLAS over the Kruger National Park, South Africa



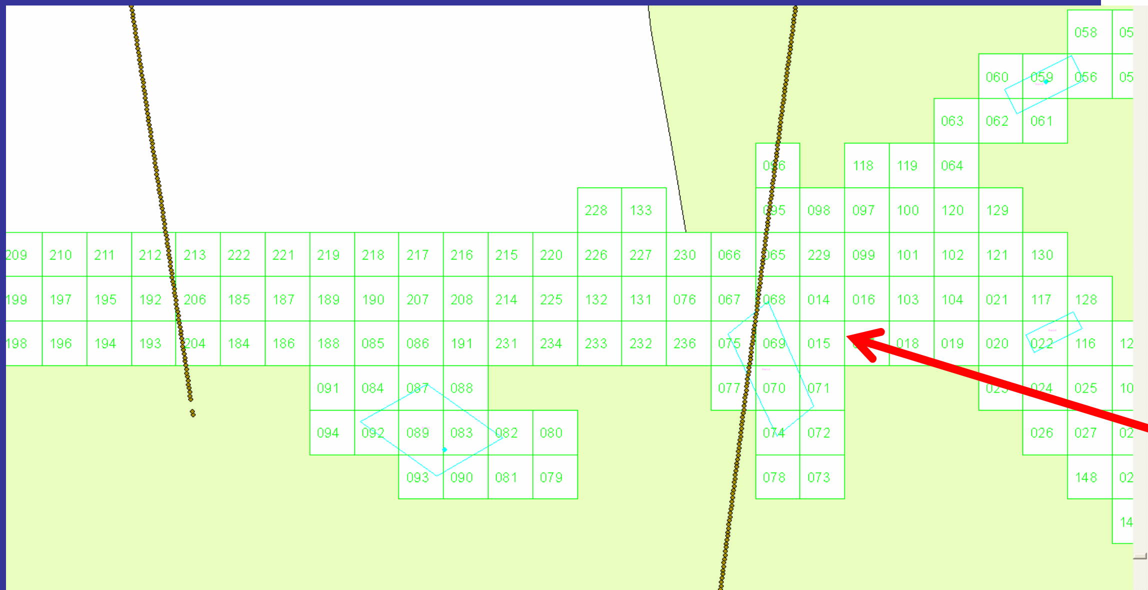
Footprint	Landscape	Woody cover percentage in the footprint area
ID_1620109334_ Shot 1	Limpopo/Luvuvhu floodplains	63.20
ID_1627010494_Shot 22	Lebombo North	73.60
ID_1627010724_Shot 18	Mixed Combretum/Terminalia sericea woodland	40.80

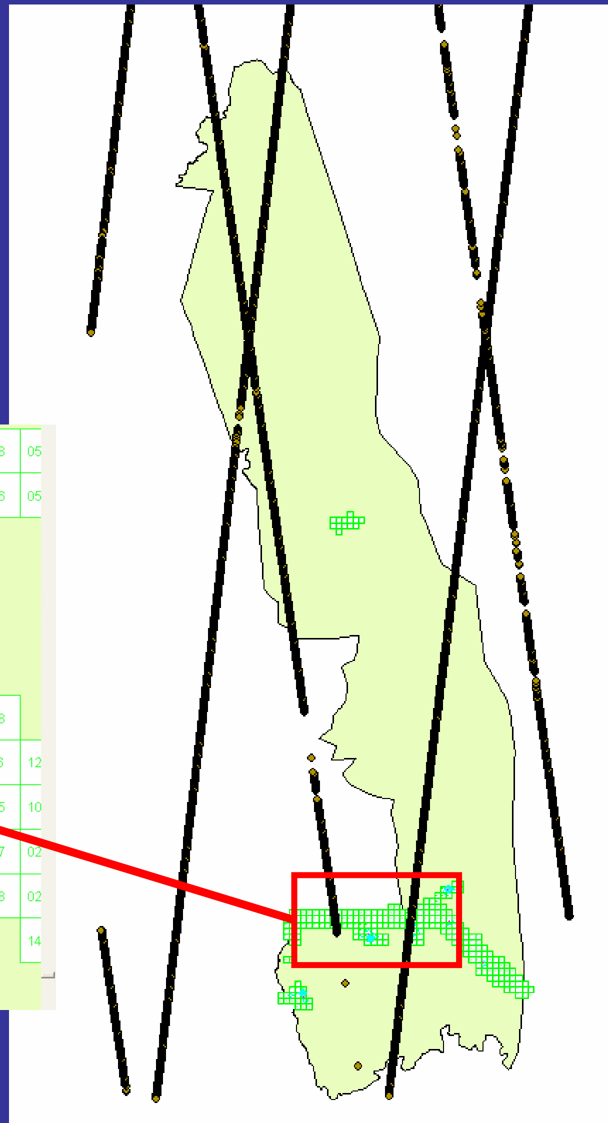
ICESAT-GLAS over the Kruger National Park, South Africa



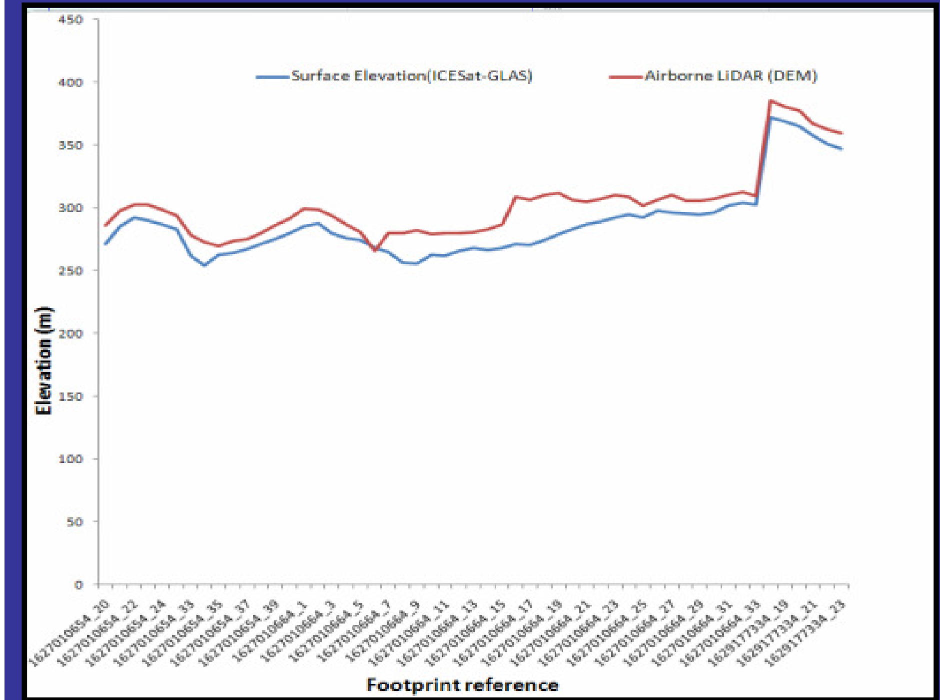
ICESAT-GLAS over the Kruger National Park, South Africa

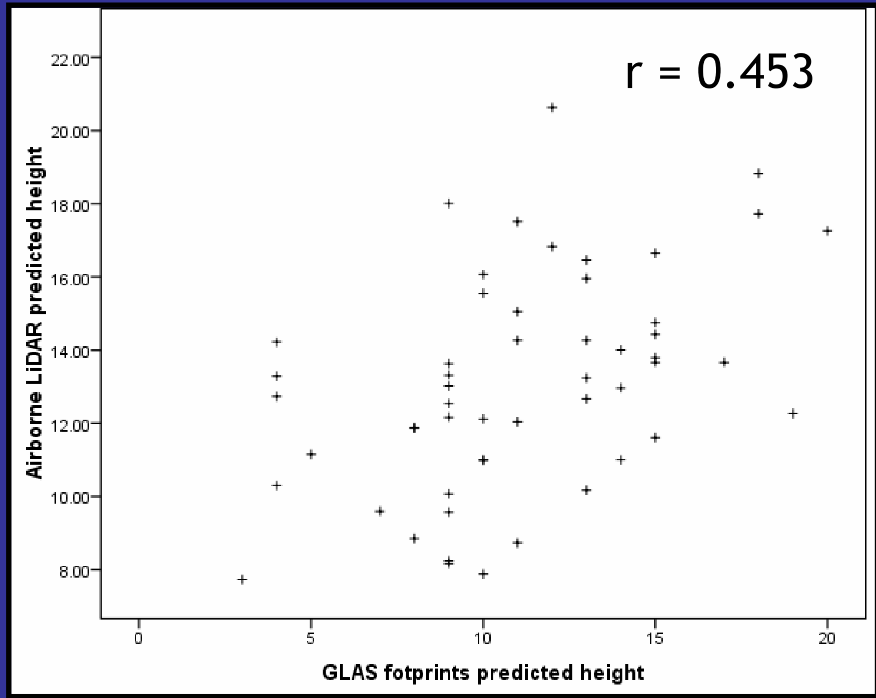
Comparing GLAS data with airborne LiDAR data for better estimation of savanna vegetation structure in the overlapping footprints.





ICESAT-GLAS over the Kruger National Park, South Africa





Ground elevation from ICESat-GLAS and airborne LiDAR data acquired by University of Witwatersrand

Relationship between ICESat_GLAS and airborne LIDAR derived terrain height estimates

APPLICATIONS: HABITAT MAPPING

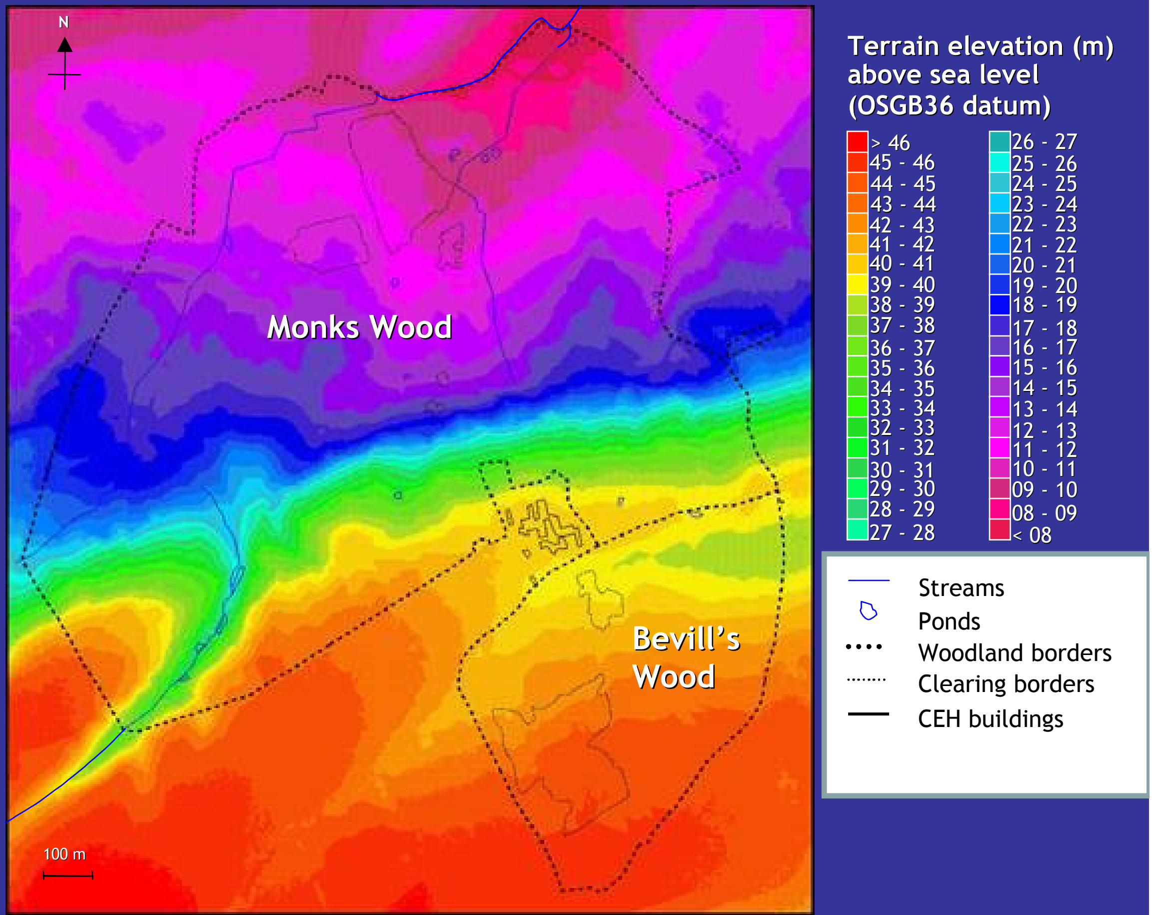
Bird habitat mapping at Monks Wood

~~CEH Centre for Ecology & Hydrology~~
~~NATURAL ENVIRONMENT RESEARCH COUNCIL~~

Bird habitat mapping at Monks Wood

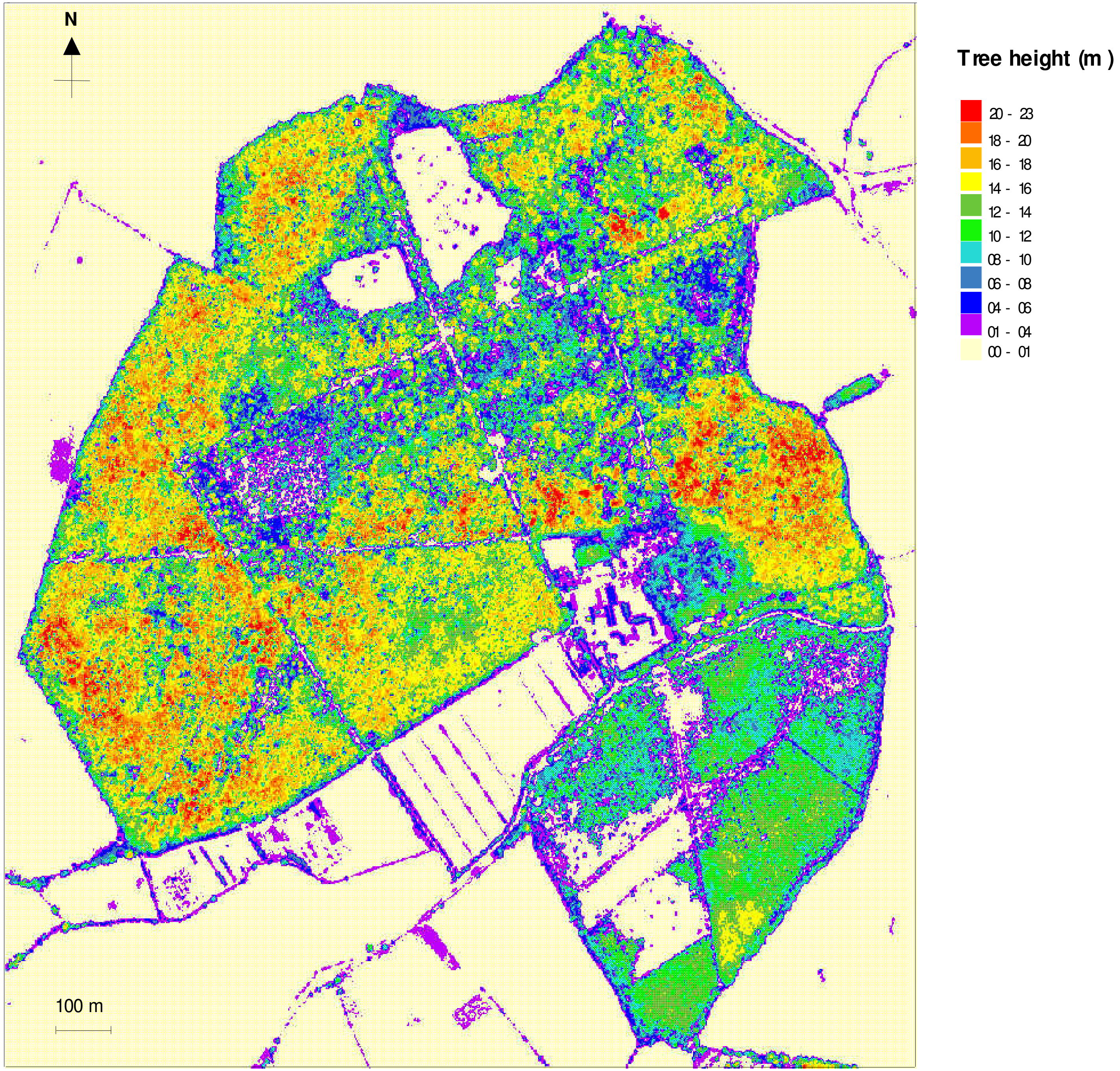
Generation of a Digital Terrain Model (DTM)

Method of production:
- adaptive morphological filtering
- thin-plate spline interpolation



1m spatial resolution

Canopy height model of Monks Wood from LIDAR



Bird habitat mapping at Monks Wood

Great Tit (*Parus major*)

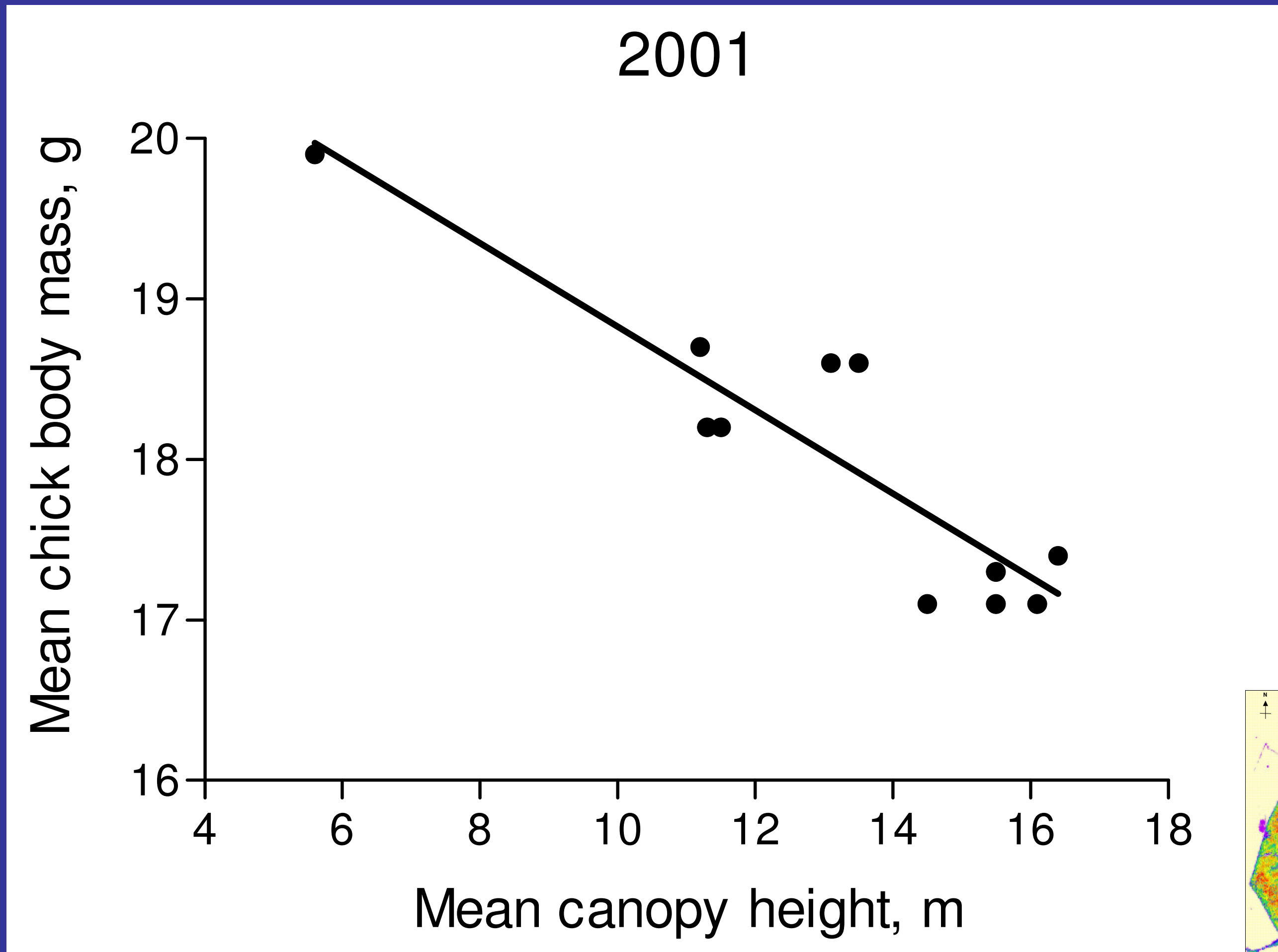
Bird habitat mapping at Monks Wood

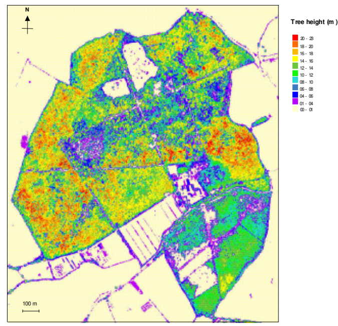
Around each nest box, mean canopy height in a 54 x 54 m window was calculated from the LIDAR canopy height model.

For each nest box, the weight of *Parus major* chicks was determined.

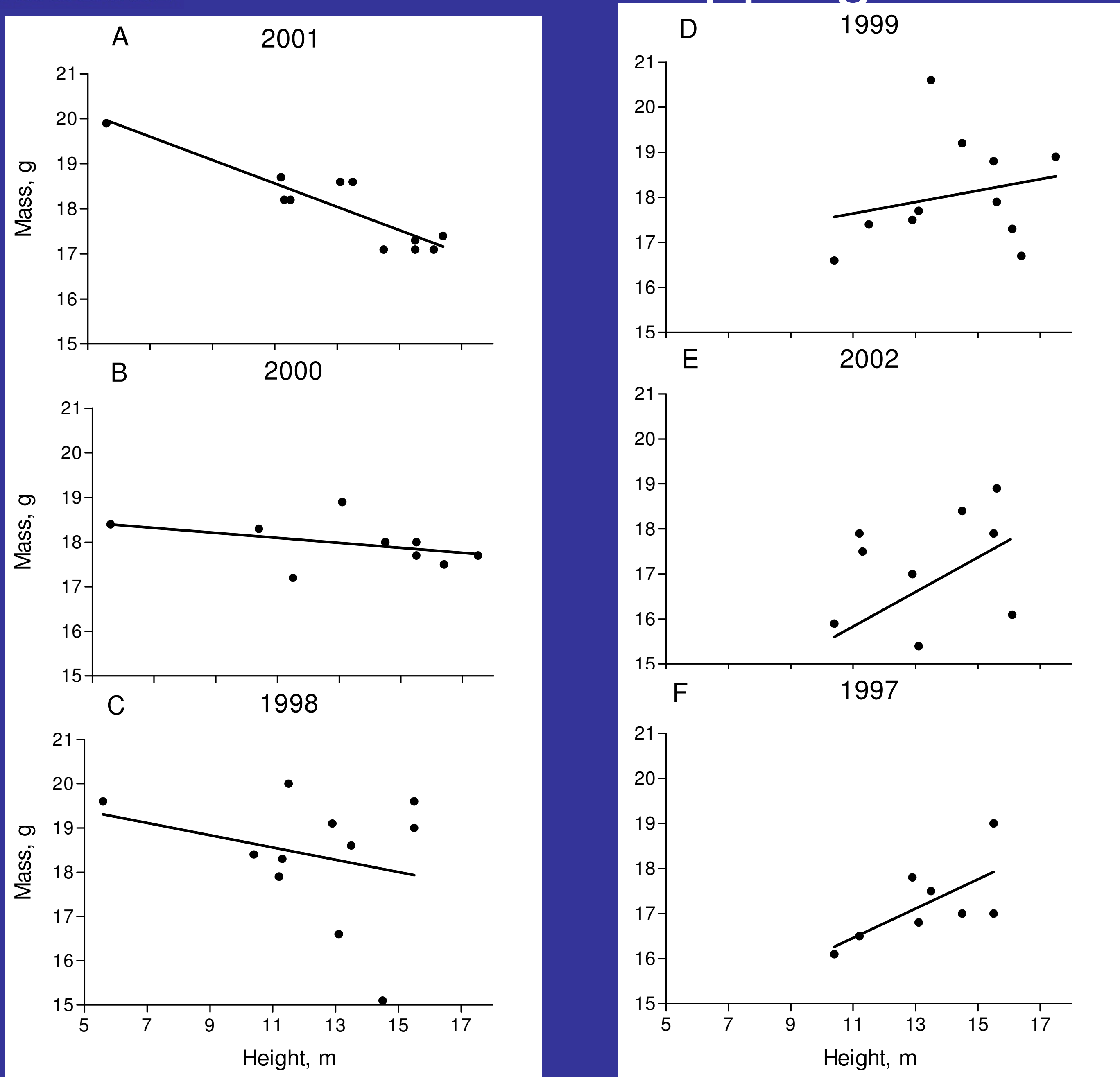
A regression of chick weight against mean canopy height was calculated for several years of chick weight data.

Bird habitat mapping at Monks Wood

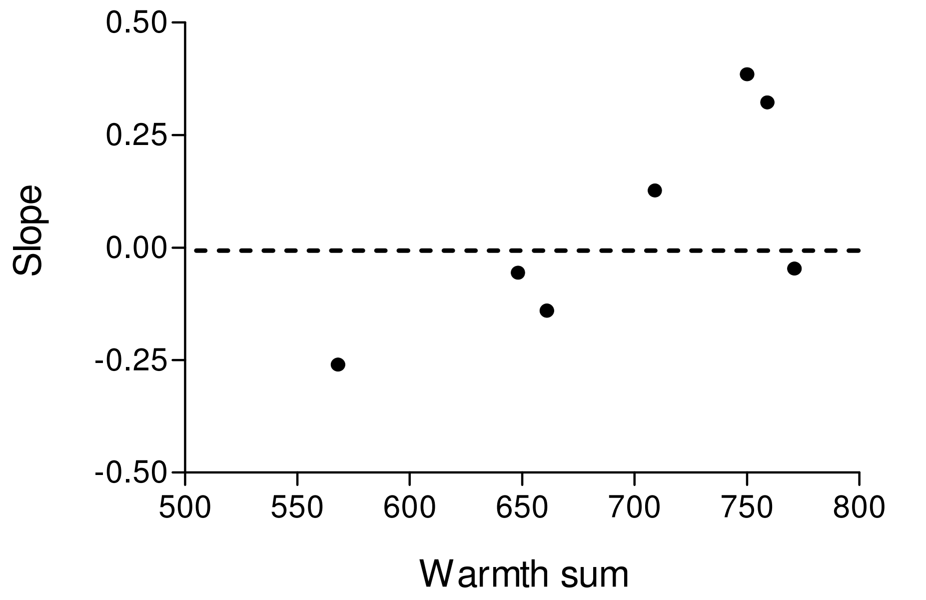




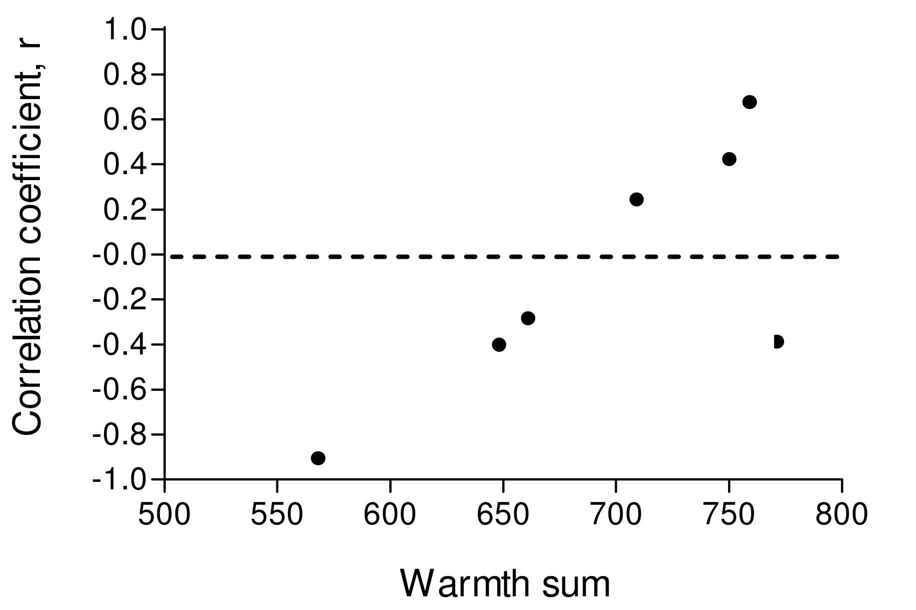
Bird habitat mapping at Monks Wood



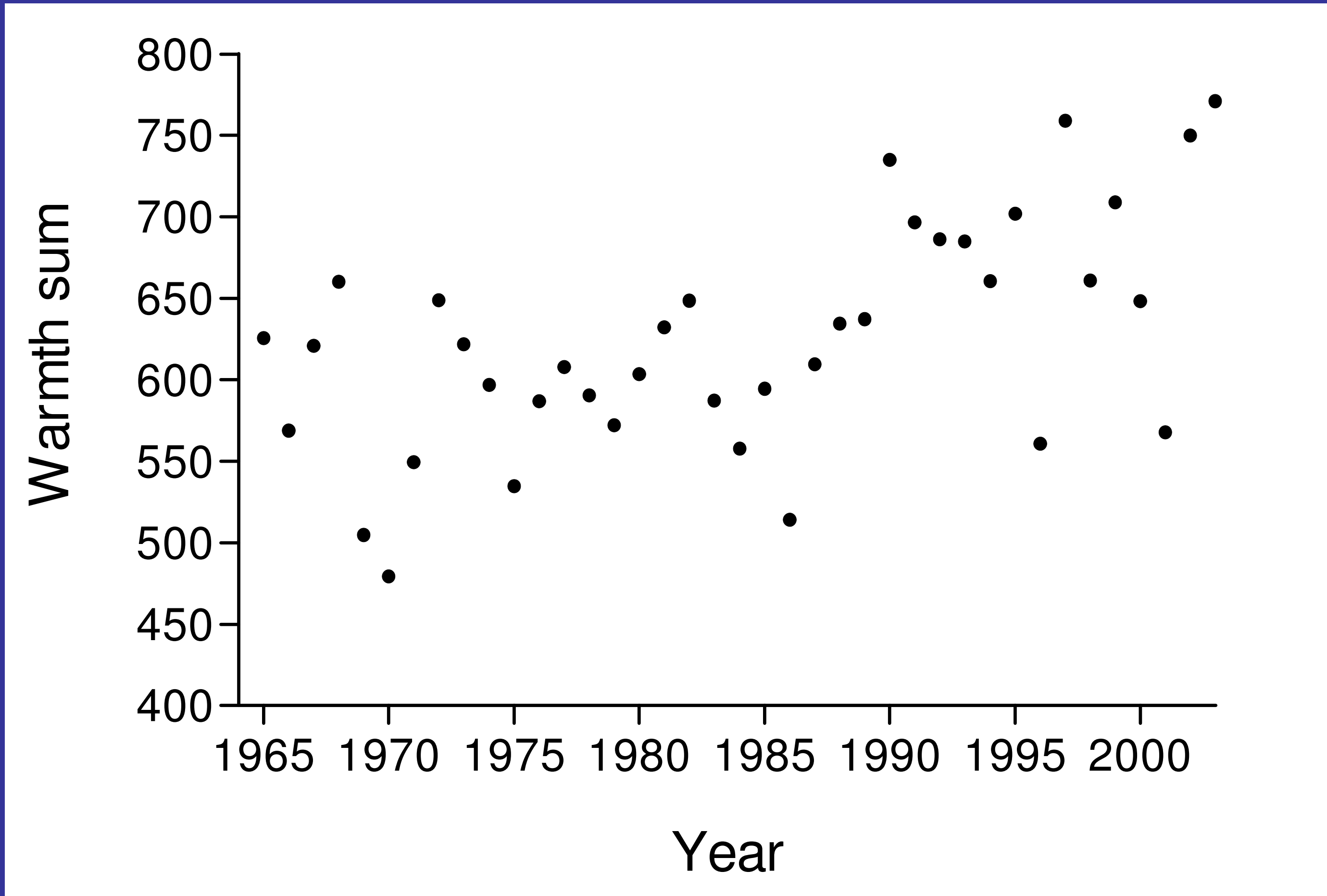
Bird habitat mapping at Monks Wood



The warmth sum is the sum of the maximum daily temperature from 1 March to 25 April.
It has been shown to be the most useful of several tested indices of spring temperature in relation to great tit breeding success (Perrins and McCleery, 1989).



Bird habitat mapping at Monks Wood

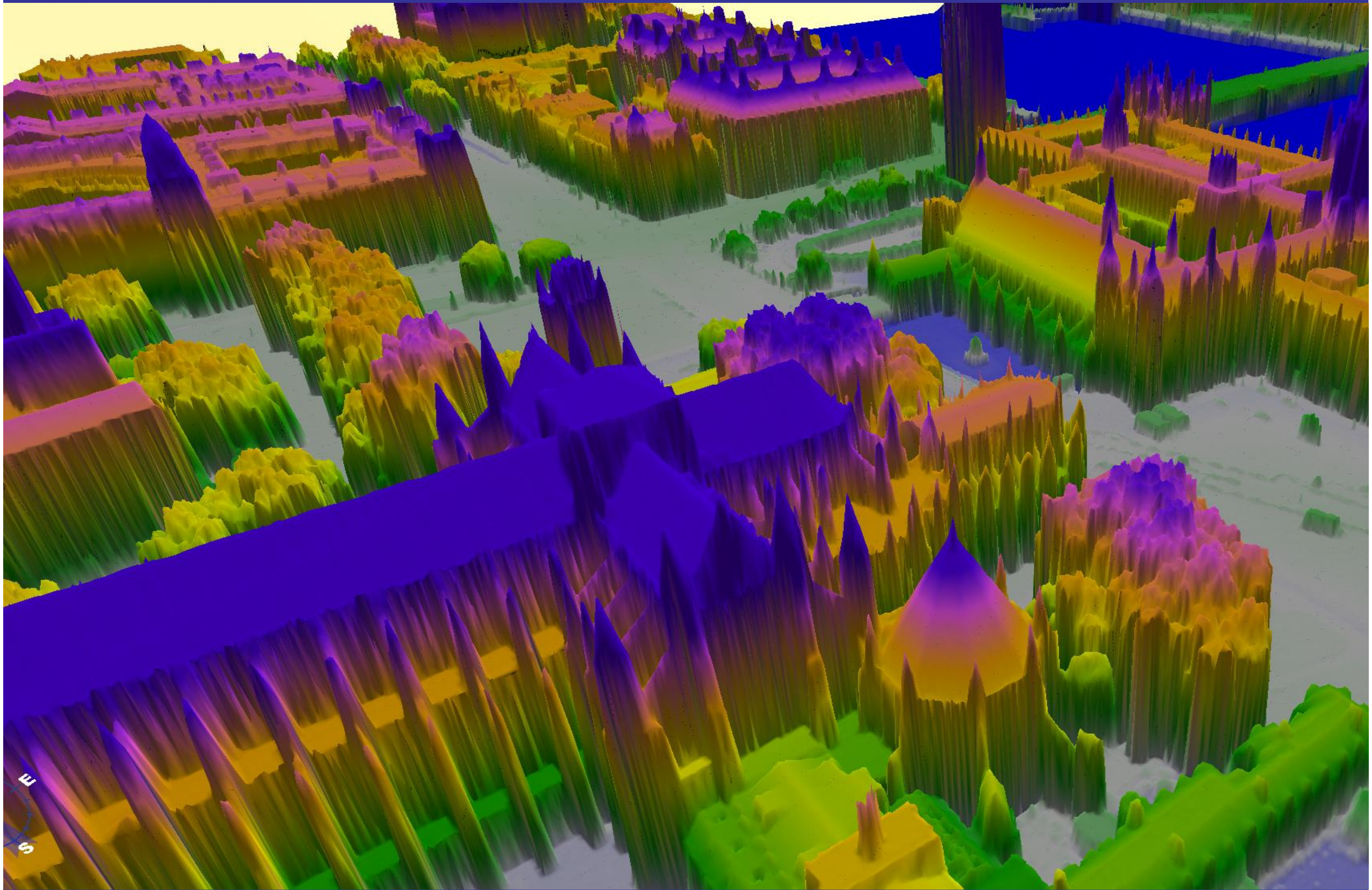


The warmth sum trend over time shows the impact of climate change.

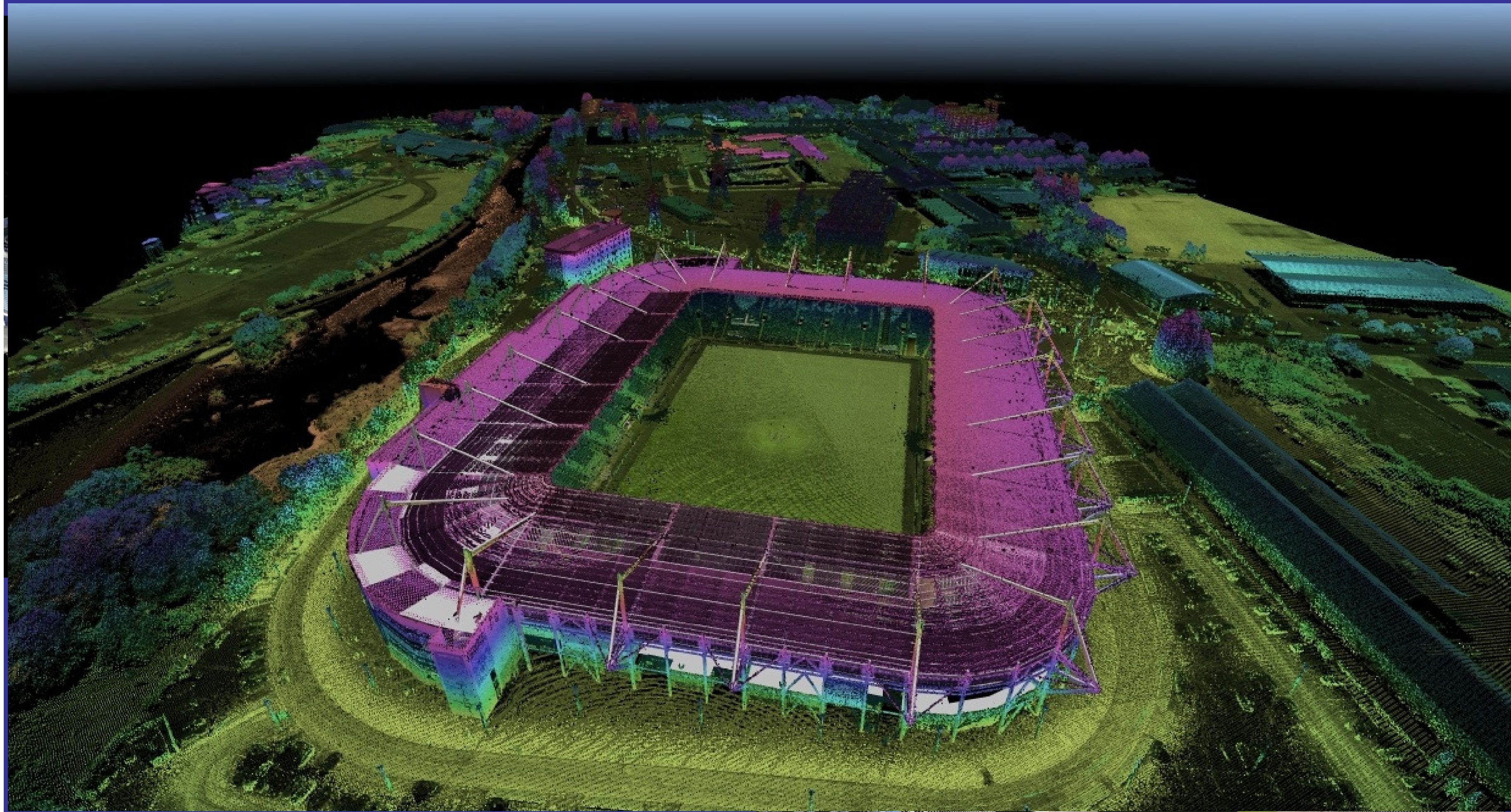
APPLICATIONS: URBAN MAPPING

University of Leicester

3D laser mapping



University of Leicester



infoterra
an EADS company

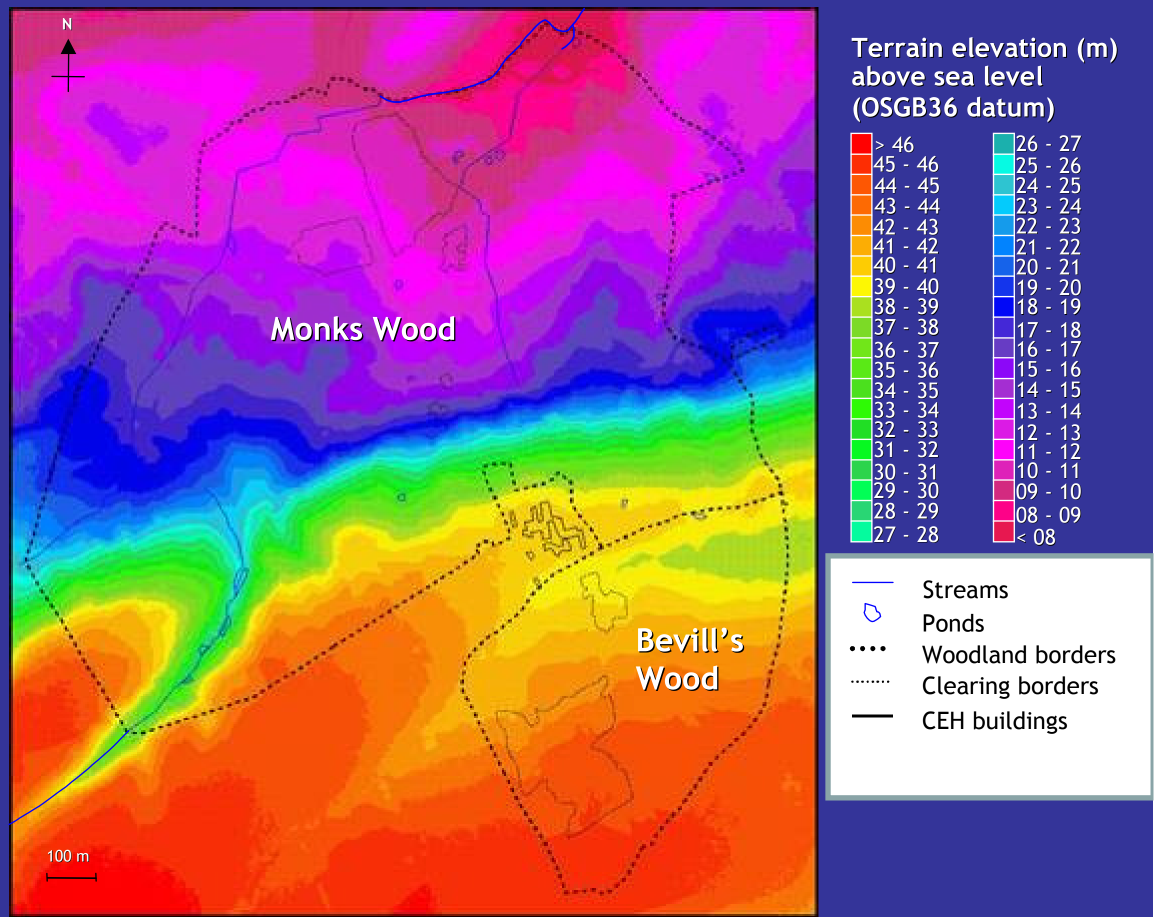
APPLICATIONS: TERRAIN MODELLING

Terrain modelling at Monks Wood

Generation of a Digital Terrain Model (DTM)

Method of production:

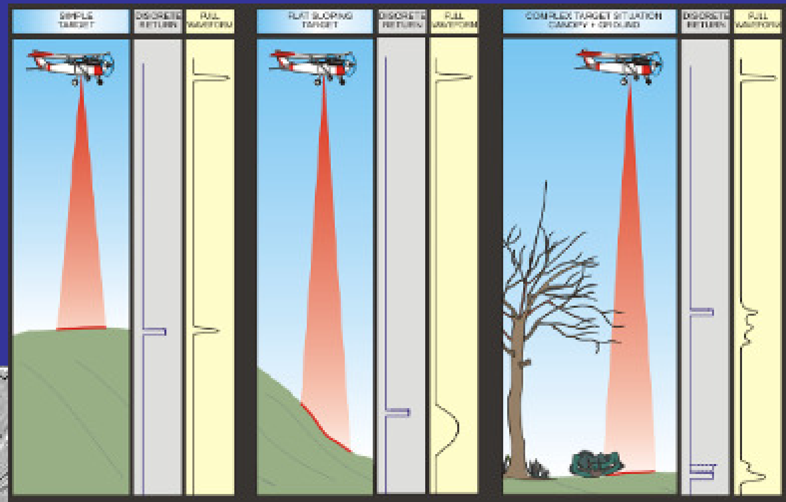
- adaptive morphological filtering
- thin-plate spline interpolation

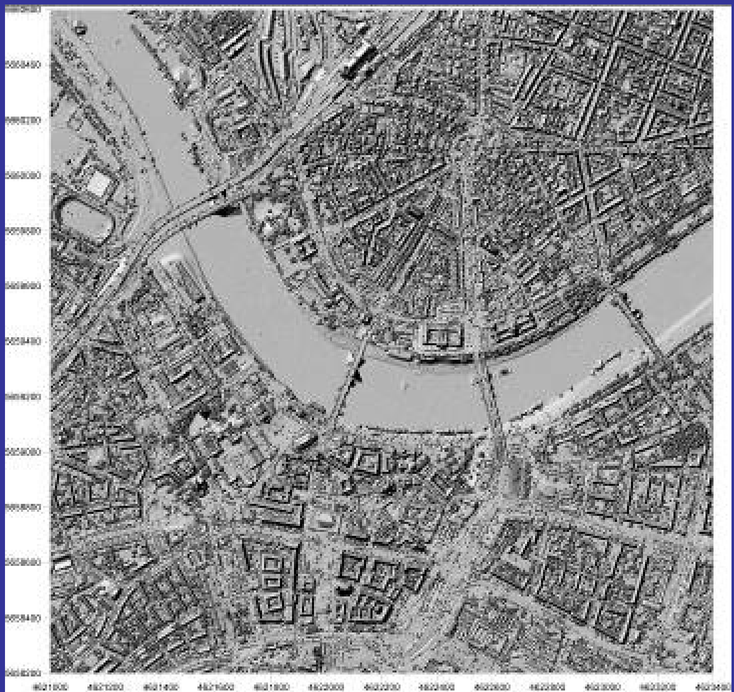


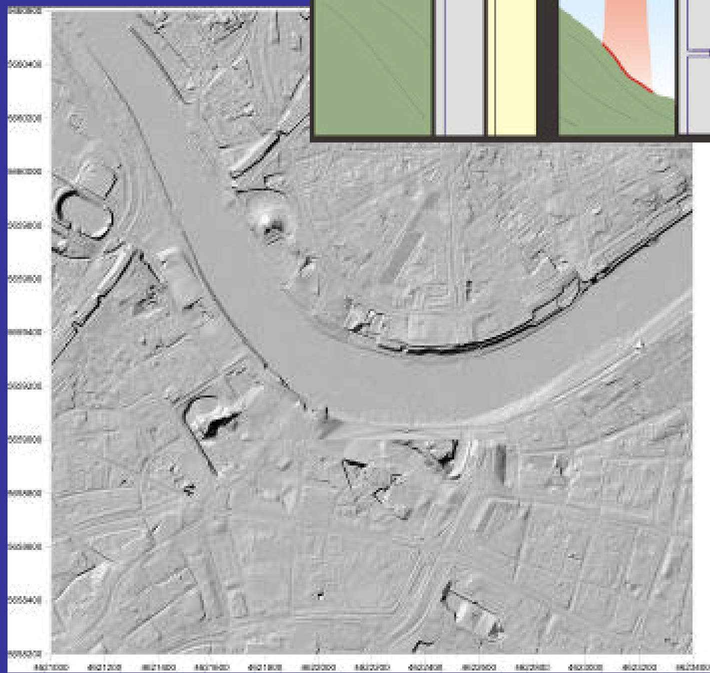
1m spatial resolution

University of Leicester

- High resolution terrain modelling ~10-15cm in z
- City modelling, disaster response, deformation
- Pulse rate: 33,000 – 100000 Hz
- Fixed or rotating wing



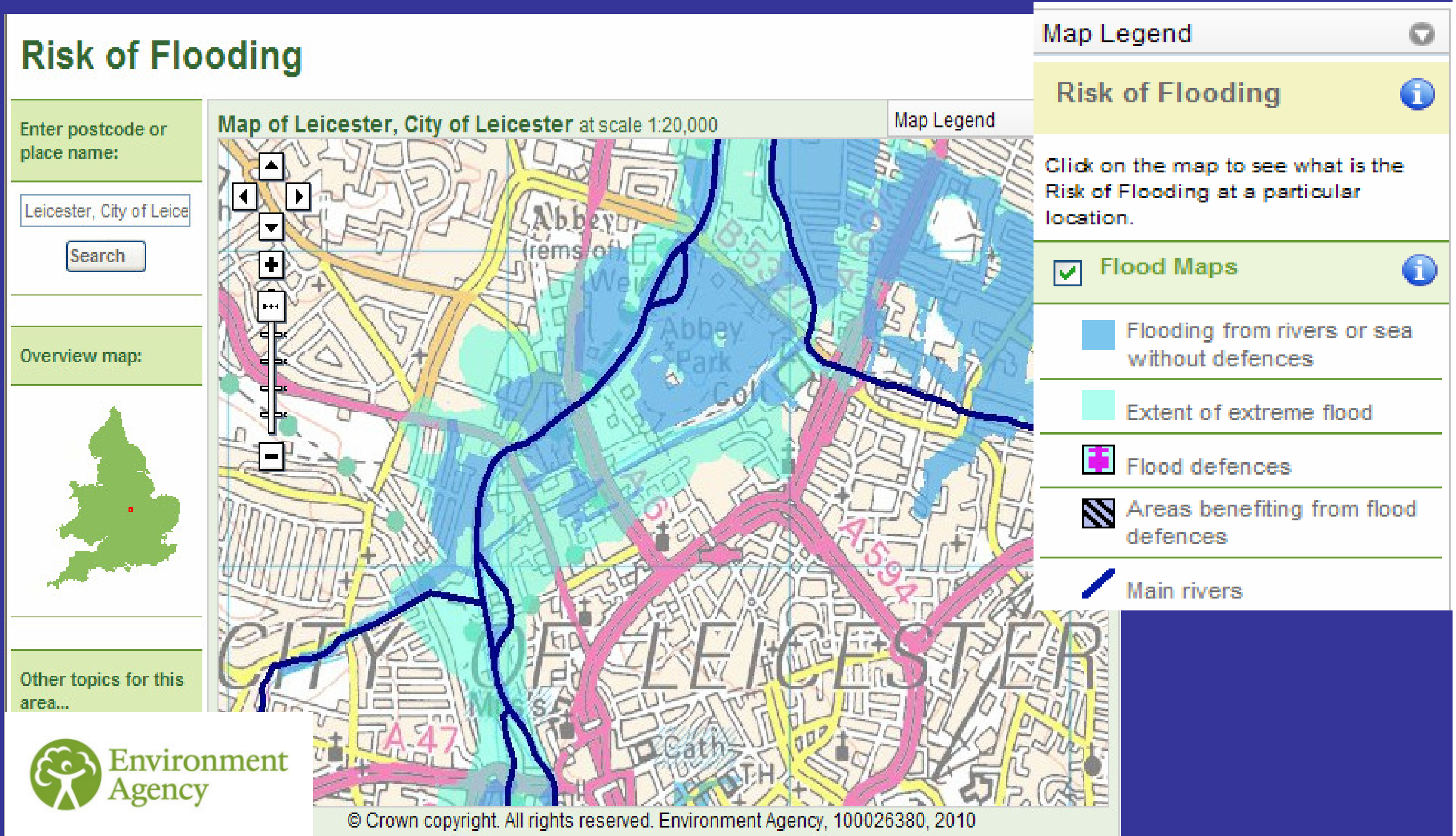


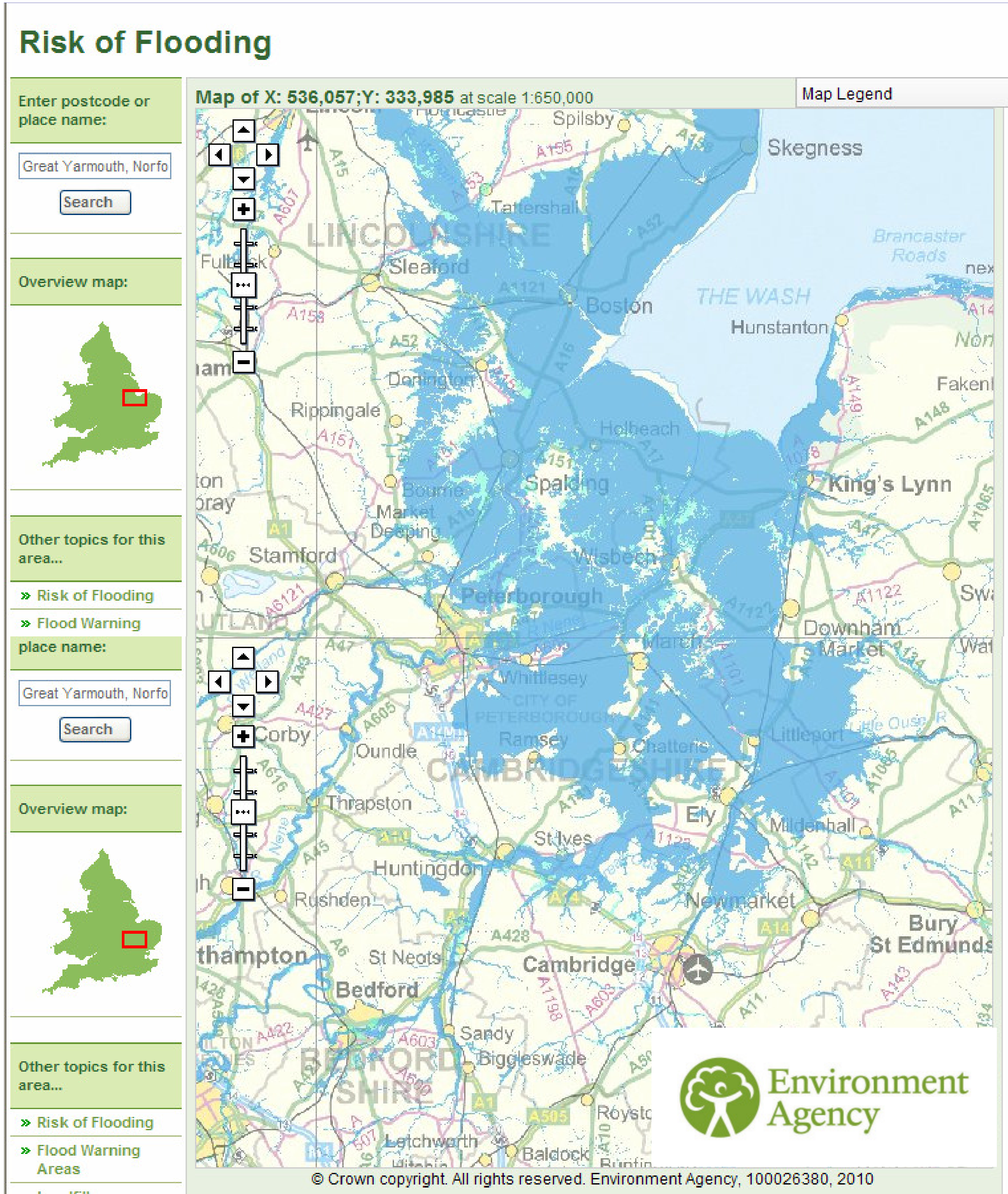


Flood risk modelling

- Environment Agency Geomatics Group LIDAR
- Spatial resolutions from 25cm to 2m
- Vertical height accuracy of 5 to 15cm
- Referenced to Ordnance Survey's National GPS Network
- Archived data covering over 62% of England & Wales, including major urban areas and rural flood plains

Flood risk modelling





Flood risk modelling

Flood risk map,

The Wash, East Anglia.

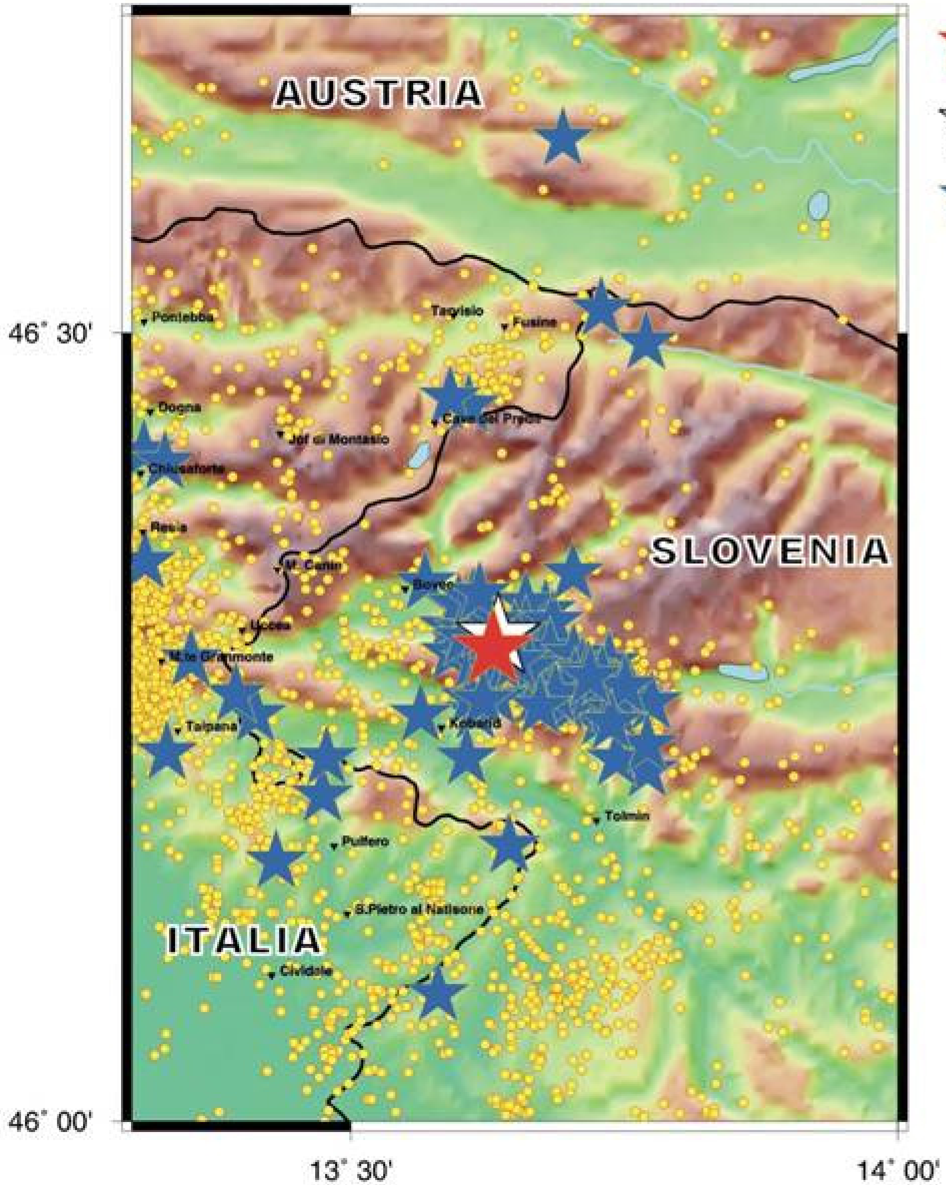
APPLICATIONS: EARTHQUAKES

University of Leicester

Application of LiDAR to mapping seismogenic faults beneath a forest canopy in mountainous terrain, southeastern Alps, Slovenia

University of Leicester

Earthquakes in Slovenia



★ M_D = 5.1 ore 15:04 del 12-07-2004

☆ M_D = 5.6 ore 11.55 del 12-04-1998 — Scossa principale / Main shock

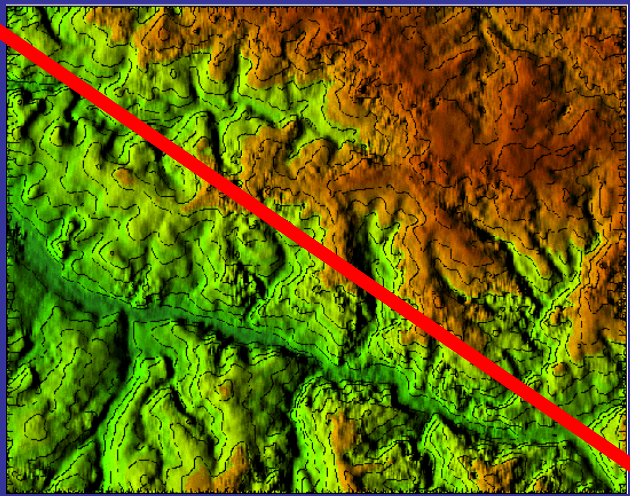
★ M_D > 3.0 — Sismicità dal 1977 a giugno 2004

● M_D < 3.0 — Seismicity from 1977 to June 2004

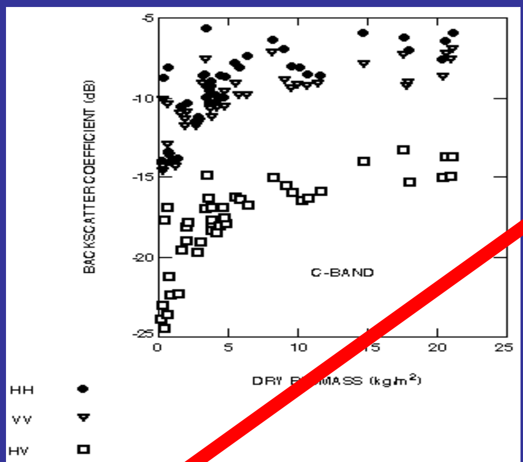
Epicentre and fault source of the 1511 M=6.8 is unclear – one of the largest recorded earthquakes in the Alps

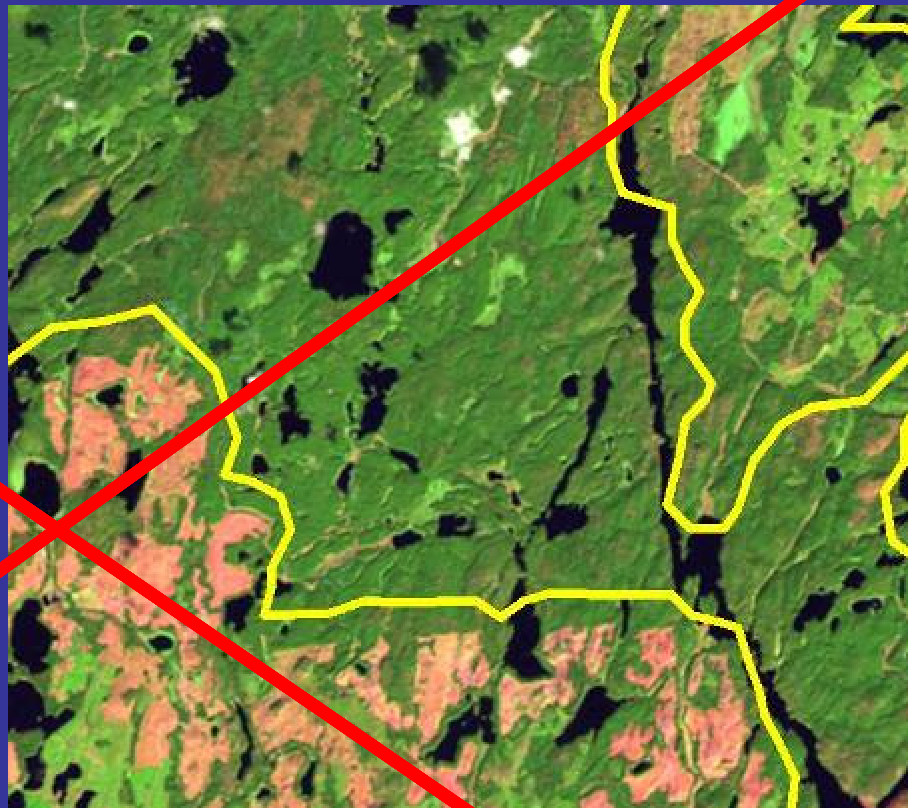
Earthquakes in Slovenia

Other Approaches



Topographic maps:
Limited spatial resolution



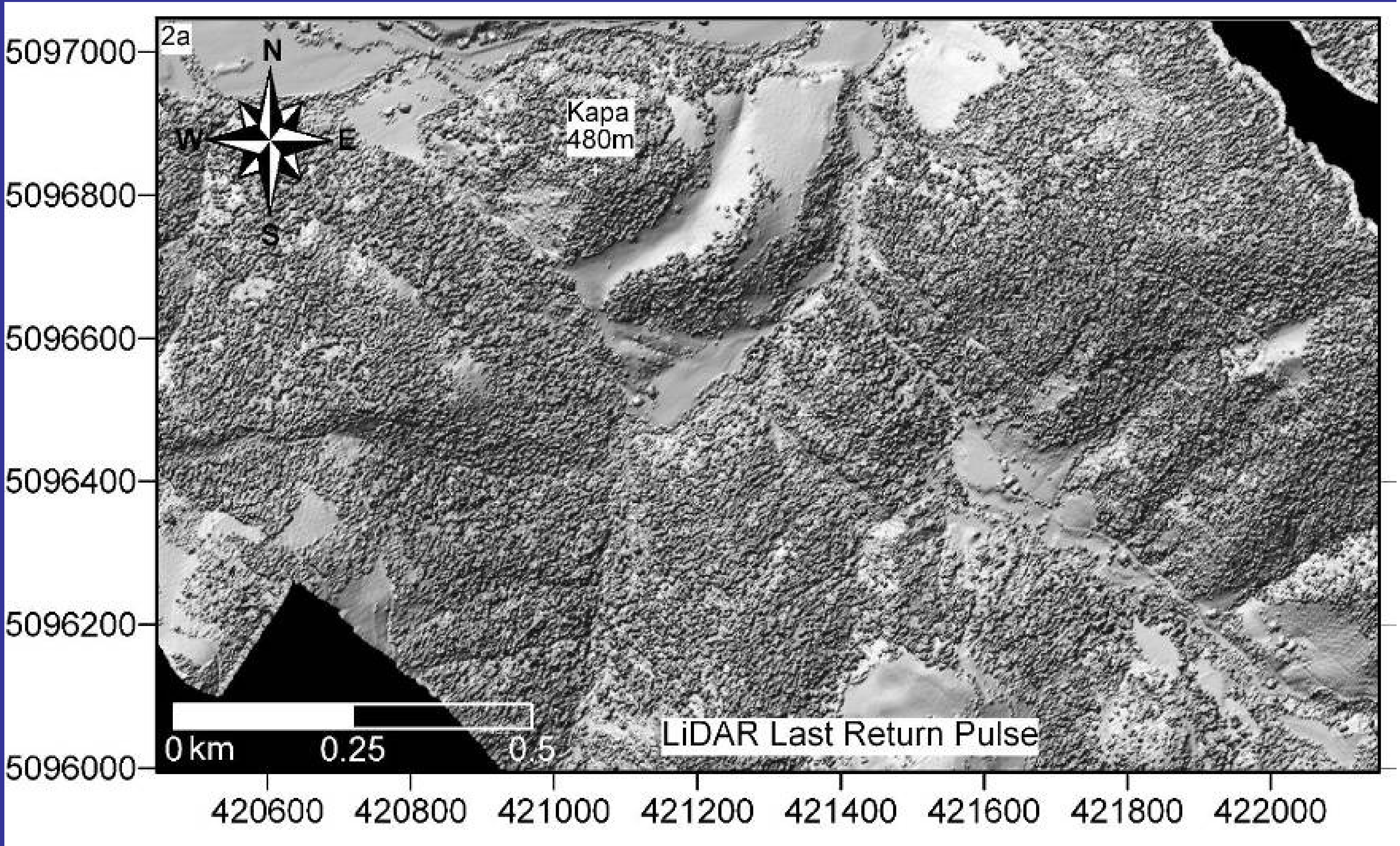


Optical imaging: Mountain shadows, spectral quality, limited spatial resolution

Synthetic Aperture Radar: Signal saturation, not enough signal return from the ground, limited spatial resolution

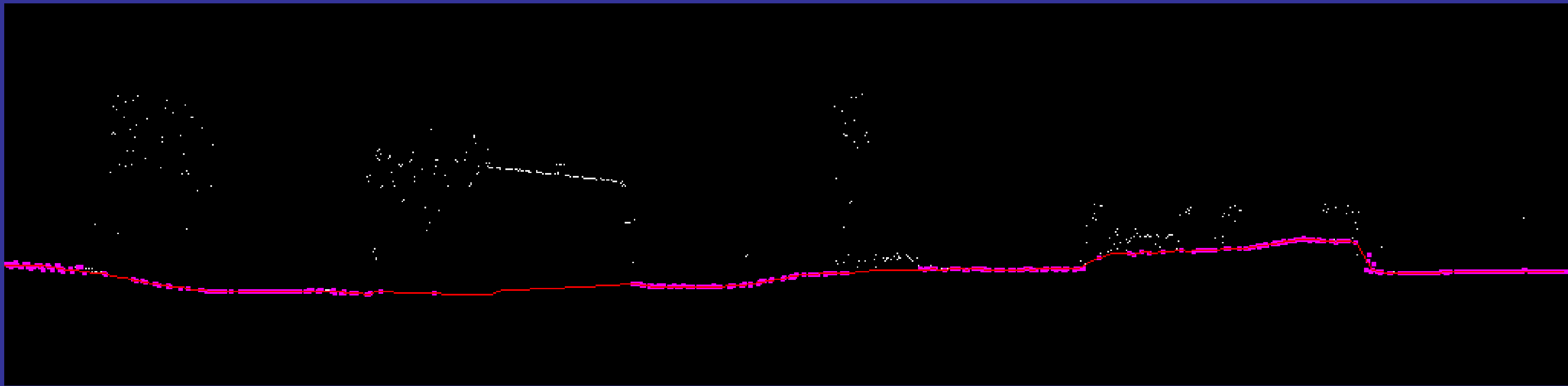
University of Leicester

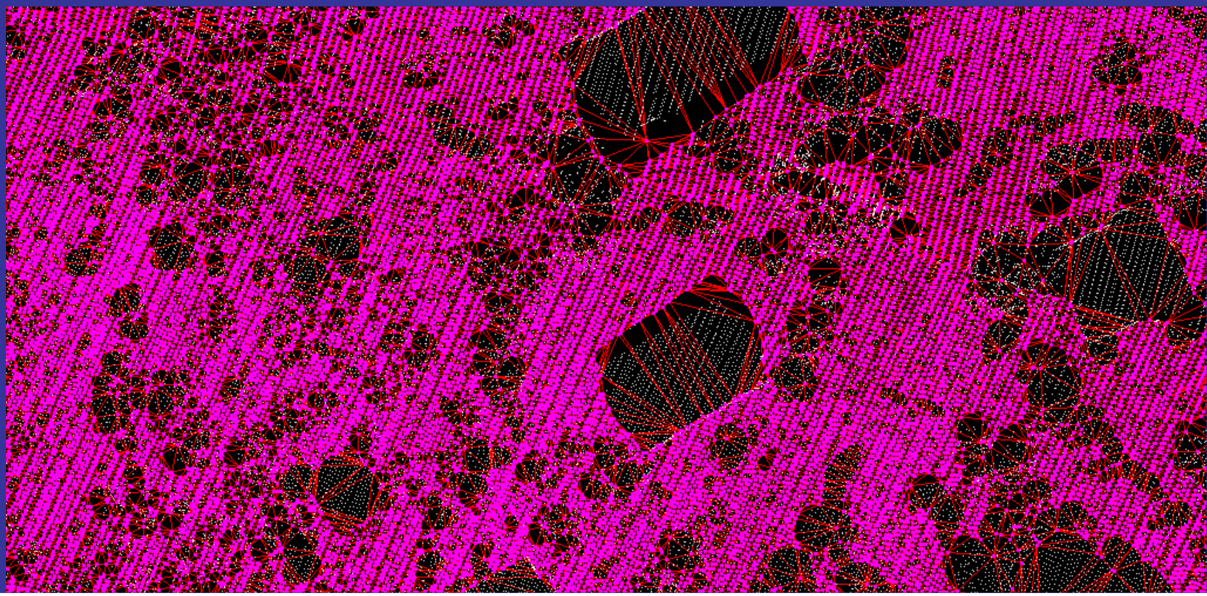
Earthquakes in Slovenia



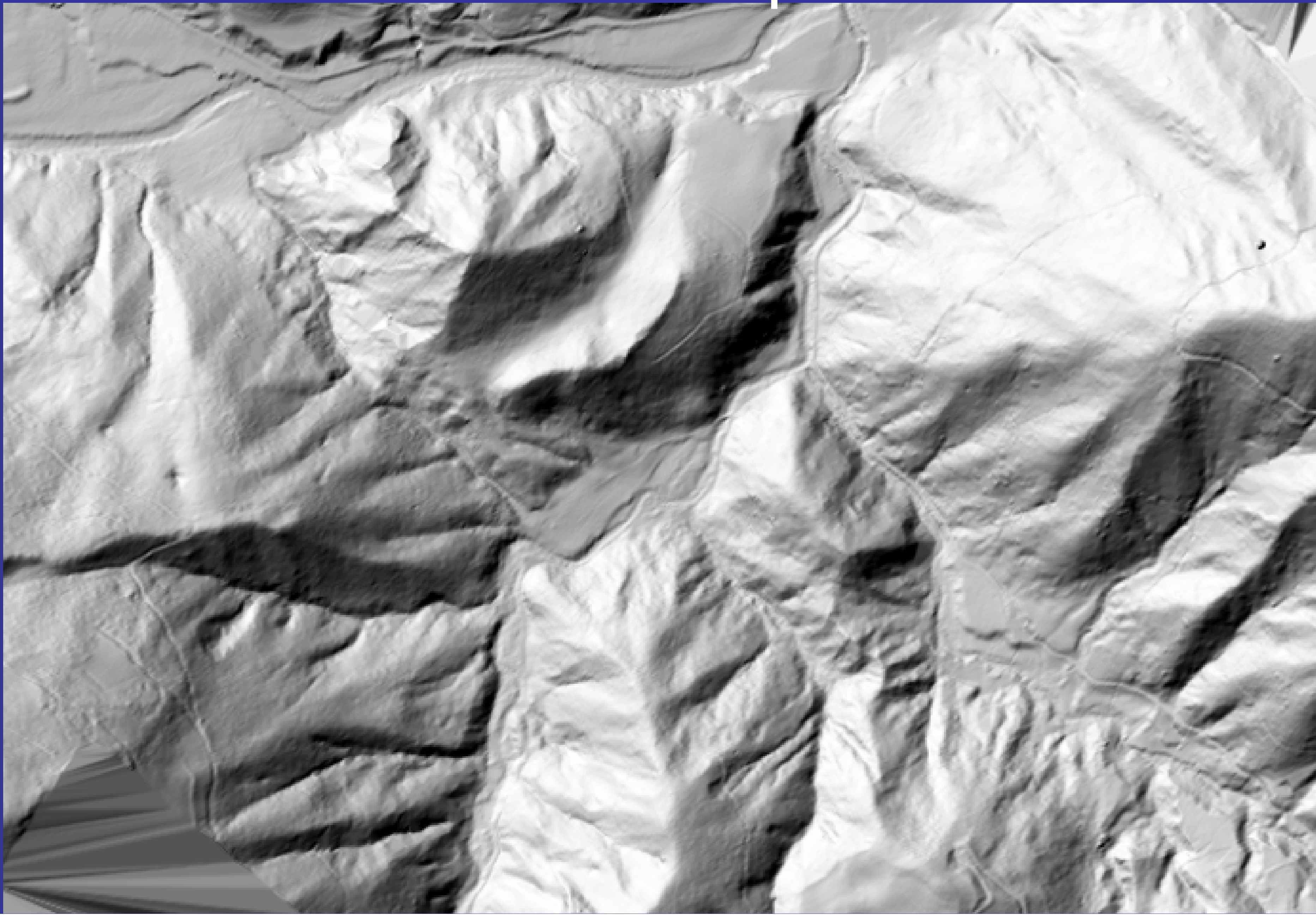
Earthquakes in Slovenia

Modelling the Ground Surface

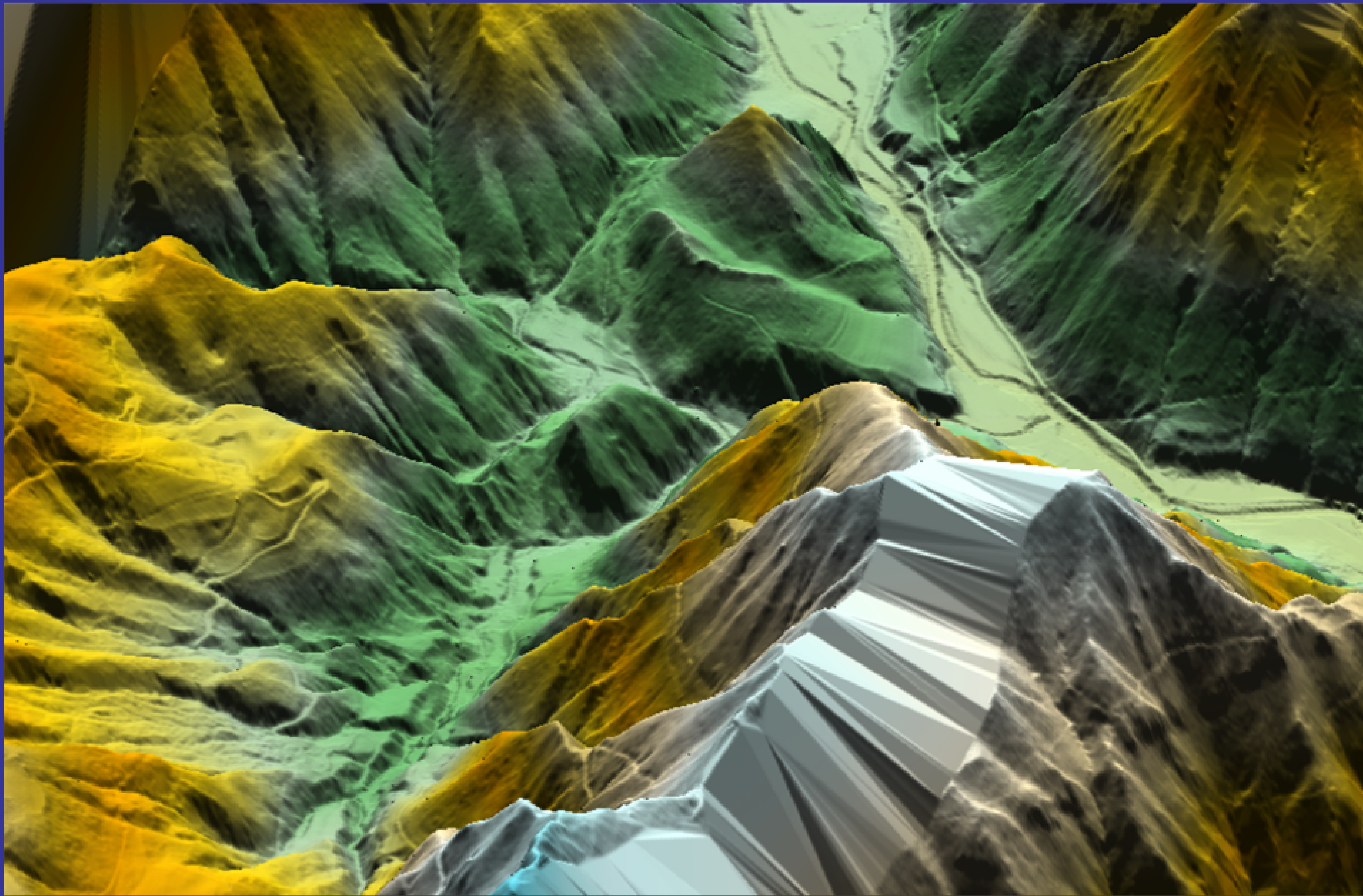




Earthquakes in Slovenia

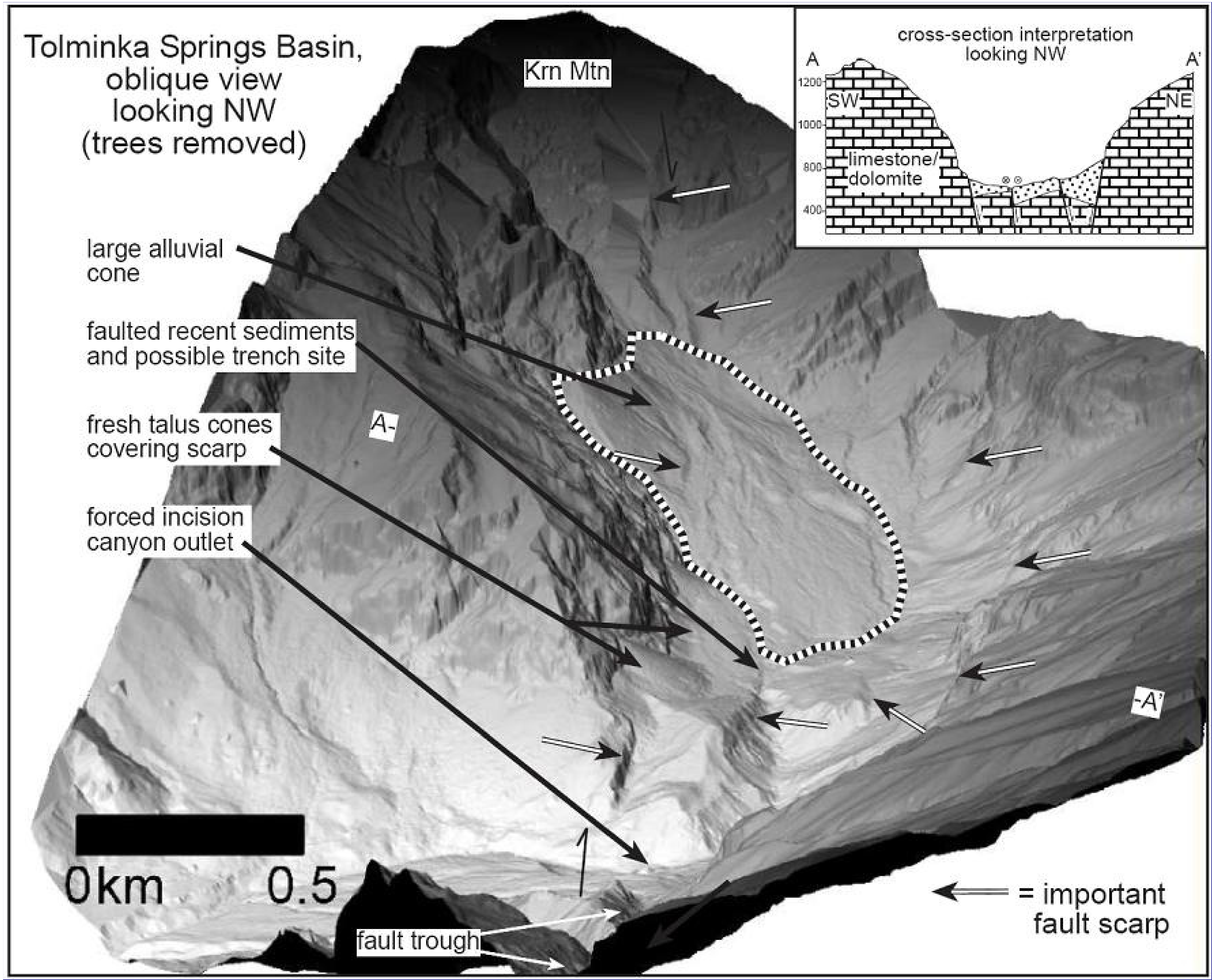


Earthquakes in Slovenia



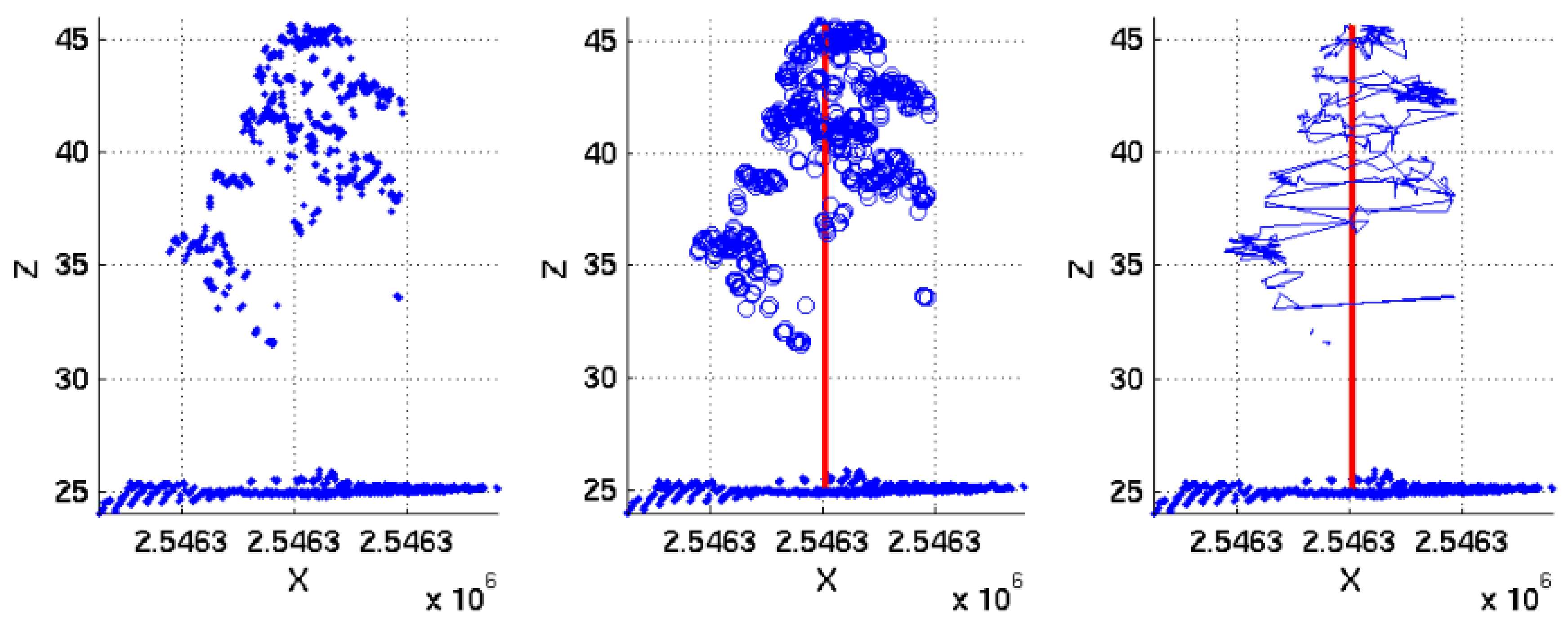
Earthquakes in Slovenia

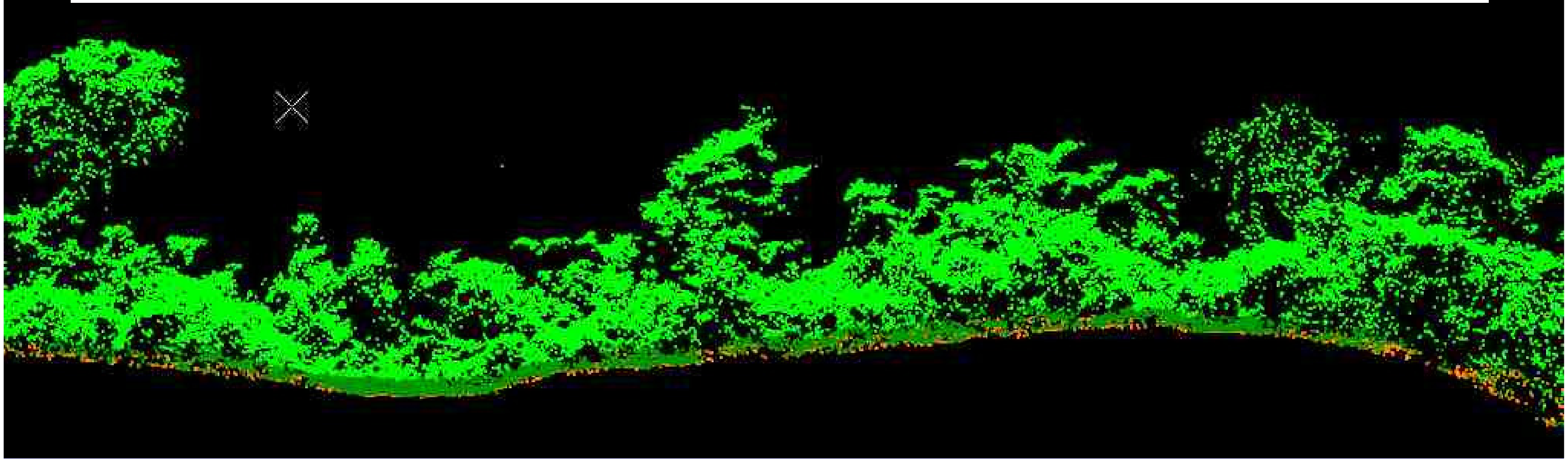
Kevin Tansey points out the detected fault line



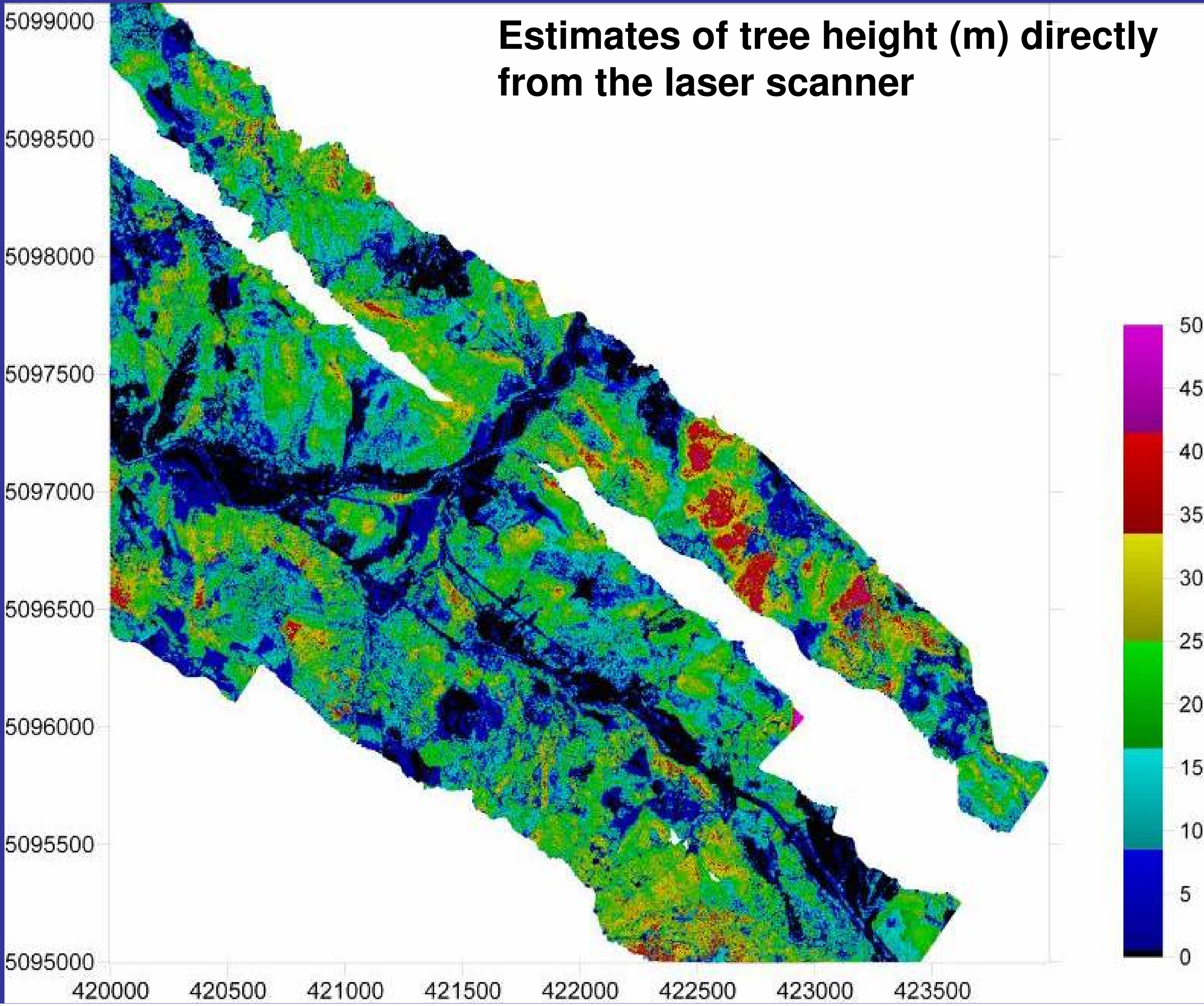
Tolminka Springs Basin, oblique view looking NW (trees removed)
Krn Mtn
cross-section interpretation looking NW
A
A'
SW
NE
1200
1000
800
400
limestone/ dolomite
large alluvial cone
faulted recent sediments and possible trench site
fresh talus cones covering scarp
forced incision canyon outlet
A-
-A'
0km
0.5
fault trough
= important fault scarp

Earthquakes in Slovenia





Earthquakes in Slovenia



Other applications of LIDAR

- Spatial planning
- Archaeological surveys
- Emergency services planning
- Environmental monitoring
- Risk assessment
- Agricultural mapping
- Wind Farm site selection

CONCLUSIONS

University of Leicester

Conclusions

- LIDAR has seen a steady expansion of application areas
- Sensor technology has vastly improved over the last decade
- Current systems are being deployed on the ground, on helicopters, planes and satellites.
- LIDAR is a field of growth, both in market terms and scientifically.

University of Leicester

Acknowledgements

- Kevin Tansey, University of Leicester
- Nick Tate, University of Leicester
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- Claire Jarvis, University of Leicester
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- Andy Anstee, Infoterra UK
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- Paul Bellamy, Centre for Ecology and Hydrology
- Ross Hill, University of Bournemouth
- Rob Fuller, British Trust for Ornithology
- Andy Gosler, University of Oxford