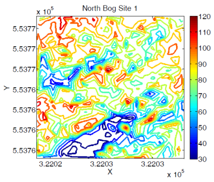
Early results from the first full waveform LiDAR survey over a lowland ombrotrophic peatland, and synthesis with hyperspectral Eagle-Hawk data



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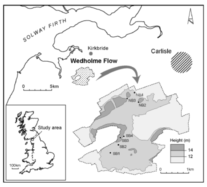
The University of Nottingham
University of Southampton
University of Exeter

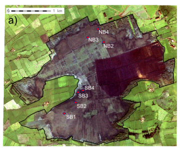
Aims of project

- Determine information content of FWL data
  - context of short sward vegetation
- Test the processing chain for FWL data
- Consider operational data processing and handling issues
  - Develop methods for processing
  - Feedback to ARSF-DAN
- Compare with existing LiDAR data from a well-instrumented site
  - Peatland site with demonstrated links between top of canopy structure and underlying hydrology / biodiversity

Study site

- Wedholme Flow, Cumbria
- Ombrotrophic peatland
- Range of condition classes
  - Wet, intact, diverse *Sphagna*
  - Dry, degraded, cut over, shrub-dominated
- Good test bed for short-sward vegetation
- NERC-funded work on LiDAR DSMs and vegetation structure showed relevance of ALS technique



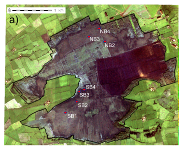


Anderson, K., J. J. Bennie, et al. (2010). "Combining LiDAR and IKONOS data for ecohydrological classification of a lowland ombrotrophic peatland." Journal of Environmental Quality **39**: 1-14.

Anderson, K., J. J. Bennie, et al. (2009). "Laser scanning of fine-scale pattern along a hydrological gradient in a peatland ecosystem." Landscape Ecology **25**: 477-492.

Relationship to NERC strategy

- Biodiversity resource
- Spatial data required for ecosystem service evaluation
- Hydrology, ecology and C sequestration linked
- "compost bomb" instability in peatlands under c.c.*
- Many relationships to NERC-banners including *climate system, biodiversity, technologies*



C. M. Luke et al. **Soil carbon and climate change: from the Jenkinson effect to the compost-bomb instability**. *European Journal of Soil Science*, 2010

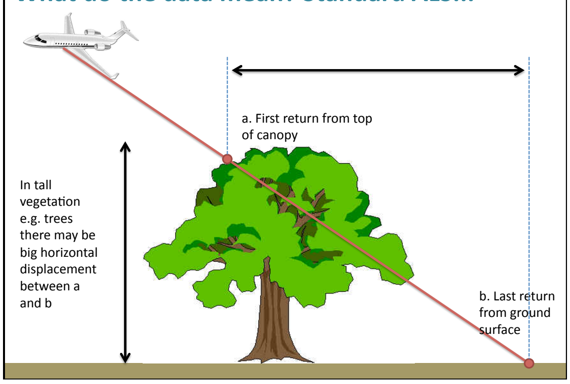
1. Data format

- Text file for every point on the land surface

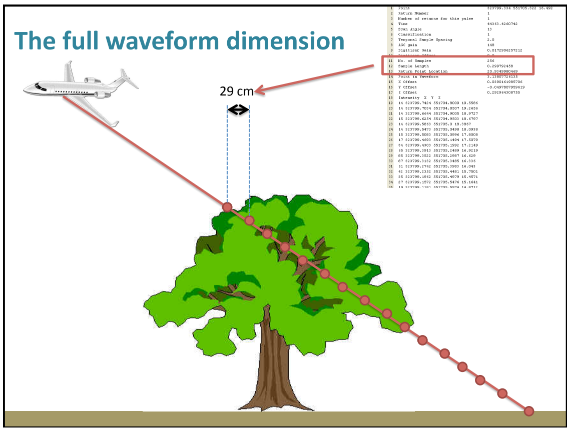
```
Point            322018.6700 553757.3100 13.6900
Scanner          101213.9132 6098554.8656 1550.1158
Time             42436.522221
Channel 1 count  256
Sample length    0.29979
Point            3.31792
Vector x         -1.316537E-005
Vector y         2.242169E-005
Vector z         1.475835E-004
Channel 1 samples
14
14
13
14
15
15
14
13
16
31
49
54
49
33
25
22
20
16
```

```
Point                              323799.334 551705.322 16.492
Return Number                      1
Number of returns for this pulse   1
Time                               44363.4260742
Scan Angle                         13
Classification                     1
Temporal Sample Spacing            2.0
AGC gain                           148
Digitiser Gain                     0.0172906257212
Digitiser Offset                   0.0
No. of Samples                     256
Sample Length                      0.299792458
Return Point Location              20.9349980469
Point in Waveform                  3.13807726135
X Offset                           0.0390161985706
Y Offset                           -0.0497807959619
Z Offset                           0.292964308755
Intensity  X  Y  Z
14 323799.7424 551704.8009 19.5586
14 323799.7034 551704.8507 19.2656
14 323799.6644 551704.9005 18.9727
15 323799.6254 551704.9503 18.6797
14 323799.5863 551705.0 18.3867
14 323799.5473 551705.0498 18.0938
15 323799.5083 551705.0996 17.8008
17 323799.4693 551705.1494 17.5079
34 323799.4303 551705.1992 17.2149
65 323799.3913 551705.2489 16.9219
85 323799.3522 551705.2987 16.629
87 323799.3132 551705.3485 16.336
61 323799.2742 551705.3983 16.043
42 323799.2352 551705.4481 15.7501
35 323799.1962 551705.4979 15.4571
27 323799.1572 551705.5476 15.1641
19 323799.1181 551705.5974 14.8712
```

What do the data mean? Standard ALS...



The full waveform dimension



Data format

- X,Y,Z co-ordinate in header for the "point"

```
Point             322018.6700 553757.3100 13.6900
Scanner           101213.9132 6098554.8656 1550.1158
Time              42436.522221
Channel 1 count   256
Sample length     0.29979
Point             3.31792
Vector x          -1.316537E-005
Vector y          2.242169E-005
Vector z          1.475835E-004
Channel 1 samples
14
14
13
14
15
15
14
13
16
31
49
54
49
33
25
22
20
16
```

```
1  Point                               323799.334 551705.322 16.492
2  Return Number                       1
3  Number of returns for this pulse    1
4  Time                                44363.4260742
5  Scan Angle                          13
6  Classification                      1
7  Temporal Sample Spacing             2.0
8  AGC gain                            148
9  Digitiser Gain                      0.0172906257212
10 Digitiser Offset                    0.0
11 No. of Samples                      256
12 Sample Length                       0.299792458
13 Return Point Location               20.9349980469
14 Point in Waveform                   3.13807726135
15 X Offset                            0.0390161985706
16 Y Offset                            -0.0497807959619
17 Z Offset                            0.292964308755
18 Intensity  X  Y  Z
19 14 323799.7424 551704.8009 19.5586
20 14 323799.7034 551704.8507 19.2656
21 14 323799.6644 551704.9005 18.9727
22 15 323799.6254 551704.9503 18.6797
23 14 323799.5863 551705.0 18.3867
24 14 323799.5473 551705.0498 18.0938
25 15 323799.5083 551705.0996 17.8008
26 17 323799.4693 551705.1494 17.5079
27 34 323799.4303 551705.1992 17.2149
28 65 323799.3913 551705.2489 16.9219
29 85 323799.3522 551705.2987 16.629
30 87 323799.3132 551705.3485 16.336
31 61 323799.2742 551705.3983 16.043
32 42 323799.2352 551705.4481 15.7501
33 35 323799.1962 551705.4979 15.4571
34 27 323799.1572 551705.5476 15.1641
35 19 323799.1181 551705.5974 14.8712
```

What is the header position and where is it located?

```
Point                               323799.334 551705.322 16.492
Return Number                       1
Number of returns for this pulse    1
Time                                44363.4260742
Scan Angle                          13
Classification                      1
Temporal Sample Spacing             2.0
AGC gain                            148
Digitiser Gain                      0.0172906257212
Digitiser Offset                    0.0
No. of Samples                      256
Sample Length                       0.299792458
Return Point Location               20.9349980469
Point in Waveform                   3.13807726135
X Offset                            0.0390161985706
Y Offset                            -0.0497807959619
Z Offset                            0.292964308755
Intensity  X  Y  Z
14 323799.7424 551704.8009 19.5586
14 323799.7034 551704.8507 19.2656
14 323799.6644 551704.9005 18.9727
15 323799.6254 551704.9503 18.6797
14 323799.5863 551705.0 18.3867
14 323799.5473 551705.0498 18.0938
15 323799.5083 551705.0996 17.8008
17 323799.4693 551705.1494 17.5079
34 323799.4303 551705.1992 17.2149
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87 323799.3132 551705.3485 16.336
61 323799.2742 551705.3983 16.043
42 323799.2352 551705.4481 15.7501
35 323799.1962 551705.4979 15.4571
27 323799.1572 551705.5476 15.1641
19 323799.1181 551705.5974 14.8712
```
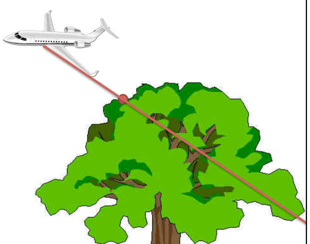
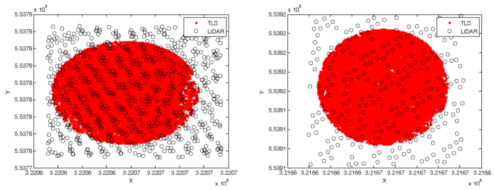



Header location value appears to be consistently from the point close to the maximum intensity of the waveform return, hence it is the first return position

2. Density of points

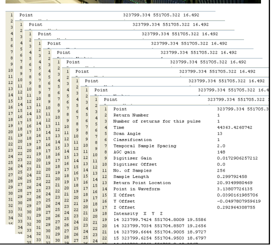
- Note that density of LiDAR points will vary depending on data capture
- Flightline overlap regions will be denser



Variable density of LiDAR hits over two different AOIs. Red dots = ground survey, Black dots = LiDAR hits

Data volumes

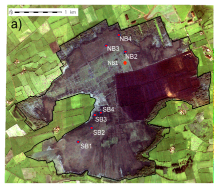
- Health warning
- 256 FW values per point (high redundancy)
- In 10 x 10 m AOI = up to 750 text files
- For entire peatland (5 x 7 km) = several million files
- Large data processing burden
- Raw text files not ready for use with standard IP software
- Requires coding capabilities (matlab, R, C etc.) to digest efficiently



Results 1: header elevation value Validation against EA LiDAR

- N=25
- 8 sites distributed across peatland

Site	Mean difference (m)
North bog 1	-0.04
North bog 2	0.08
North bog 3	-0.10
North bog 4	-0.02
South bog 1	-0.10
South bog 2	-0.14
South bog 3	-0.25
South bog 4	-0.11
Mean	**-0.09**



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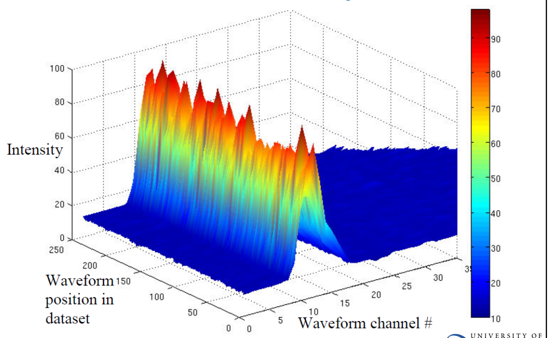
Results 2: Basic waveform analysis



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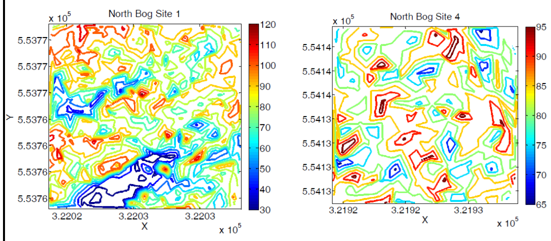
Using Matlab, it is possible to plot the spatial patterns in waveform characteristics



- Contour plots of peak intensity values in the waveform.
- Lower values = blue, higher values = red

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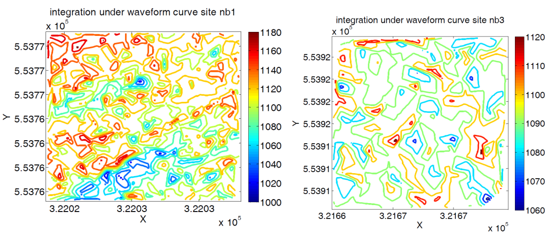
Using Matlab, it is possible to plot the spatial patterns in waveform characteristics



- Contour plots of waveform integral
- Lower values = blue, higher values = red

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Interesting patterns at NB1

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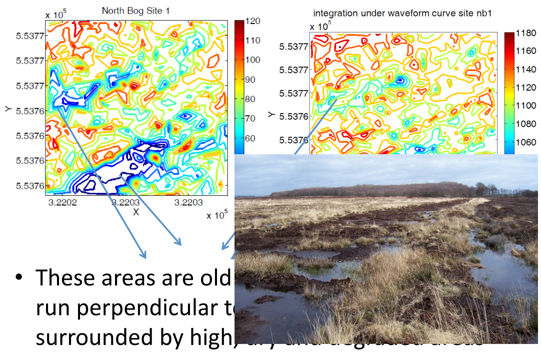

- These areas are old run perpendicular t surrounded by high

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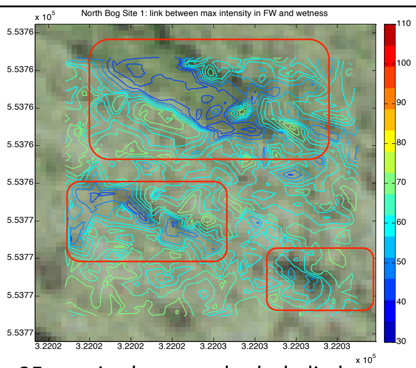

Overlaid on 25 cm air photograph, dark ditches can clearly be seen in areas of low FWL response

Stage 3: enter hyperspectral...

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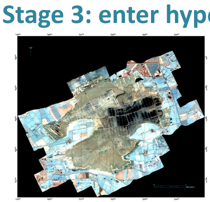
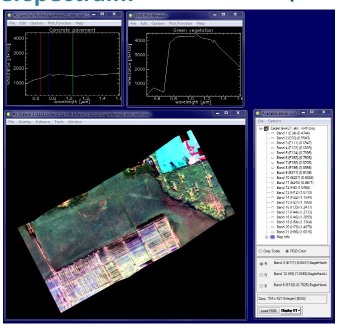


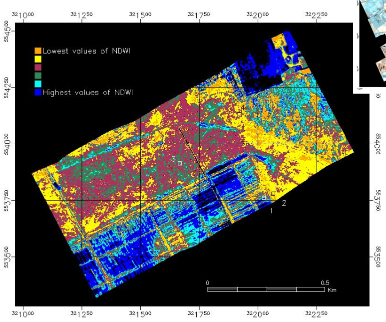
- Hawk mosaic

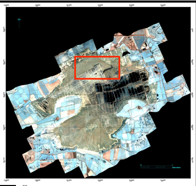


- Atmospherically corrected using ATCOR-4

Water band index

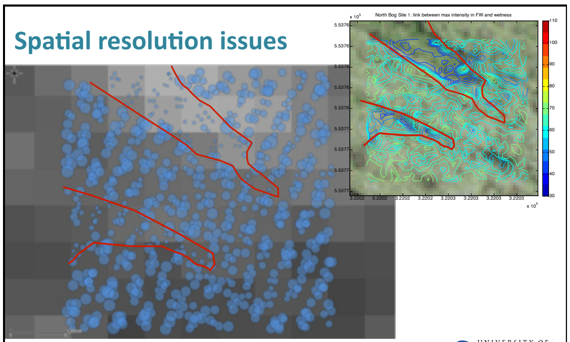
$NDWI = (R860 - R1240)/(R860 + R1240)$





Southampton

Spatial resolution issues



- Large dots = high FW max values
- Smaller dots = low FW max values

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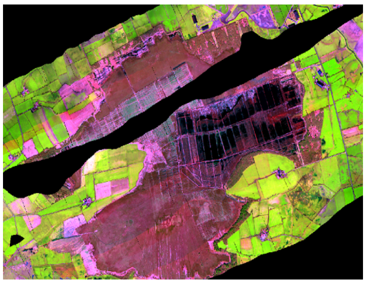
Hyperspectral / FWL classification

The University of Nottingham



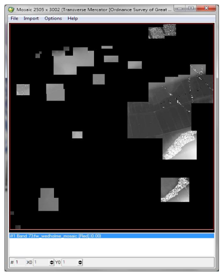
Note: this work performed prior to the ATCOR-work undertaken at Southampton but it shows the efficacy of the combined FWL and hyperspectral approach

Hyperspectral image showing the gap in coverage due to a header error. This image contains AISA Eagle/Hawk bands: 361, 162, 121.

Data used in Classifications

The University of Nottingham

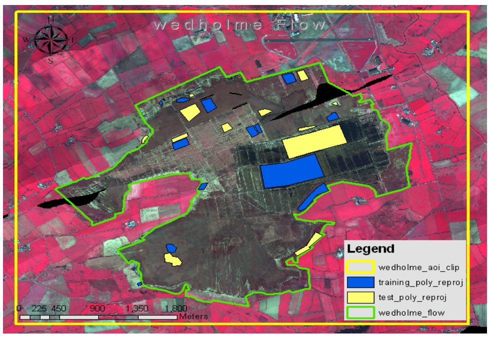
- Raw full waveform lidar: 256 return echoes (signal intensity and elevation) per scan point
- Metrics of full waveform lidar: Set of 5 metrics (sum (representing the area under the curve), minimum value, maximum value, range (difference between the min and max), and the mode) per scan point
- Hyperspectral data: 10 band minimum noise fraction (MNF) image



Disjointed Full waveform LiDAR raster, each region covers either a testing or training site.

Training data (Anderson et al (2010))

The University of Nottingham

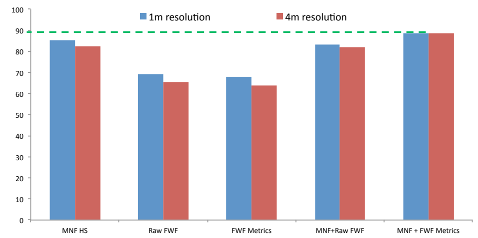


Classification using Support Vector Machines

- The SVM used in this study was performed in ENVI© using a radial basis function as described in Melgani & Bruzzone (2004).
- The gamma in kernel function was set at the default value of 1/number of bands
- a penalty parameter of 100
- no pyramid levels
- classification probability threshold was set to 0.

The University of Nottingham

Overall Classification Accuracies (%)



Analysis per class (4m SVM classification)

	Optimal Dataset	Classification accuracy (%)
Active raised bog	MNF HS + FWF metrics	98.0
Active raised bog, degraded	MNF HS + Raw FWF	96.9
Drained and degraded (Calluna dominated)	Raw FWF	32.0
Drained and degraded (Erica dominated)	MNF HA + FWF metrics	25.0
Carr woodland	MNF HS + Raw FWF	98.7
Bracken	MNF HS + Raw FWF	35.3
Tussock grassland (Molinea dominated)	MNF HA + FWF metrics	63.8
Milled unvegetated peat	MNF + FWF metrics	92.6
Eriophorum bog	Raw FWF	97.0

In each case the optimal dataset for classification always includes a full wave form dataset, either in combination with the hyper-spectral dataset or exclusively.

Conclusions

- Full waveform LiDAR data have high volume
  - Processing effort / requirement beyond standard RS
- We have presented results based on a few focused sites
  - Rolling this out over full extent is difficult
- Resolution difference between LiDAR point and hyperspectral data
- Initial results suggest that FWL intensity is proxy for near surface moisture

Recommendations to ARSF

- I would suggest that higher level product retrieval from FWL data could be an ARSF-DAN focus for the future
  - x,y,z product of maximum intensity
  - X,y,z product of waveform integral
  - X,y,z product describing waveform shape & extent
- For many users this would be the most efficient way of integrating this additional information into classifications etc.

Acknowledgements

- ARSF-DAN
  - Emma Carolan
  - Mike Grant
- MSc students
  - Cheyne Hadley (Notts)
  - Chris Koster (Exeter)