Short Term Scientific Mission Report
COST Action OPTIMISE: ES1309

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STSM topic: Scaling CH4 fluxes using hyperspectral and multispectral data in Arctic tundra ecosystems

STSM reference number: ECOST-STSM-ES1309-250515-069842
STSM type: Regular (from United Kingdom to The Netherlands)

Period: from 2016-02-26 to 2016-03-05

Host: Dr. M.J. Ferreira Dos Santos
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Room 1101B
3584 CS UTRECHT
The Netherlands

Purpose of the STSM

The purpose of this visit was to a) provide me with essential mentoring and guidance in remote sensing data and analysis for the upscaling of GHG fluxes across Arctic tundra; b) utilize expertise and facilities at Utrecht University to complete the critical analyses for key components of my PhD research and c) collaboratively work on manuscripts.

Description of the work carried out during the STSM

Maximum 2 pages

This study will be one of the first to create and utilize fine-scale vegetation maps of tundra vegetation allowing us to upscale plot scale GHG fluxes to the landscape scale. To do so we sampled four locations in Alaska along a 300km gradient from North to South, at locations where eddy covariance towers are located. These towers provide the methane flux data and the STSM work was to derive vegetation maps to link to the methane flux data. During the STSM, 3 different vegetation maps were created, which were based on expert knowledge, field spectroscopy, and automated k-means classification.

Expert knowledge vegetation maps:

For this map I used the information from the field to determine which vegetation classes occur in the tundra landscape. I then used a panchromatic (0.7m resolution) WorldView2 satellite image as a base layer to draw by hand the vegetation classes within the 300m radius footprint around each eddy covariance tower. This map was created using ArcGIS v10.1 (ESRI, Redlands, California). To support this vegetation map I used a combination of fine-scaled vegetation community analysis, walk-over surveys and ground-truthing dGPS (Trimble R7, Trimble Navigation Limited, Sunnyvale, CA, USA) measurements of known vegetation communities within the footprint (186 points for Barrow, 75 points for Atqasuk and 150 points for Ivotuk).

Field spectroscopy vegetation map

Field spectroscopy (hyperspectral) data was obtained for 5 tundra vegetation communities during the summer 2014 using UniSpec Dual channel (DC) spectrometer (http://ppsystems.com/unispec-dc/). We collected between 25 and 90 spectral signatures of each vegetation community, from 400 to 1100 nm.
To assess whether arctic tundra vegetation is separable via their reflectance across the electromagnetic spectrum we used two different clustering techniques. First we used an ANOVA to determine which region(s) of the electromagnetic spectrum allowed to separate vegetation communities by their reflectance values. Once the region(s) were defined, a principal components analysis (PCA) was used on the reflectance data of the selected spectral bands. The PCA allows to determine whether tundra vegetation communities are separable. We then used linear discriminant analysis (LDA) as a classifier of vegetation communities per site. We applied the resulting LDA classification model to a multispectral WorldView2 image (2.0m resolution) to create the field spectroscopy-derived vegetation map.

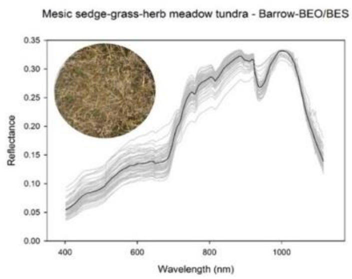
K-means unsupervised classification vegetation map

We used the multispectral WorldView2 image data and applied a k-means unsupervised classification algorithm to the 300m radius area around each flux tower to produce a vegetation map. This method was conducted using ENVI (Exelis Visual Information Solutions, Boulder, CO, USA). Initially we set the number of classes (k) to ten categories to capture the majority of the variation within the data, and used 100 iterations to create the initial vegetation map. Then we grouped classes that represented similar vegetation communities, and produced the final vegetation map.

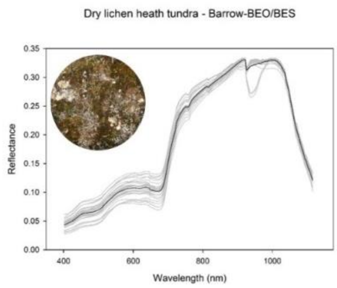
Description of the main results obtained

Maximum 4 pages

Vegetation data and field spectroscopy: Arctic tundra vegetation community spectra were similar due to high community variation as many species occur < 1 m apart (Figures 1, 2 and 3).



(a)



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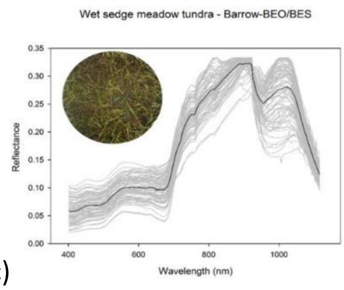
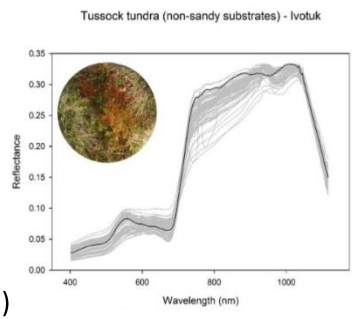
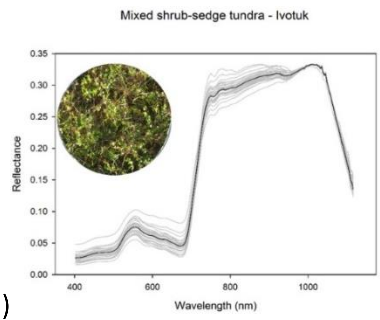


(c)

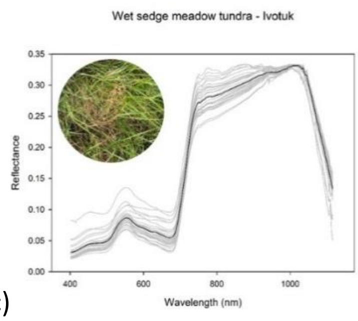
Figure 1. Spectral profile for each of the vegetation communities/types in Barrow.



(a)

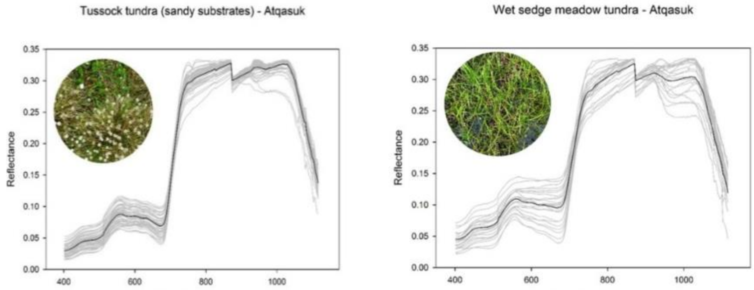


(b)



(c)

Figure 2. Spectral profile for each of the vegetation communities/types in Ivotuk.



(a) (b)

Figure 3. Spectral profile for each of the vegetation communities/types in Atqasuk.

ANOVA on field spectroscopy: The vegetation communities' reflectance was significantly different reflectance in the blue (450-510nm), red (630-690nm) and red edge (705-745nm) (Figure 4). The blue and red regions are associated with photosynthetic light absorption by plants. Furthermore, the red edge region is a metric of chlorophyll content.

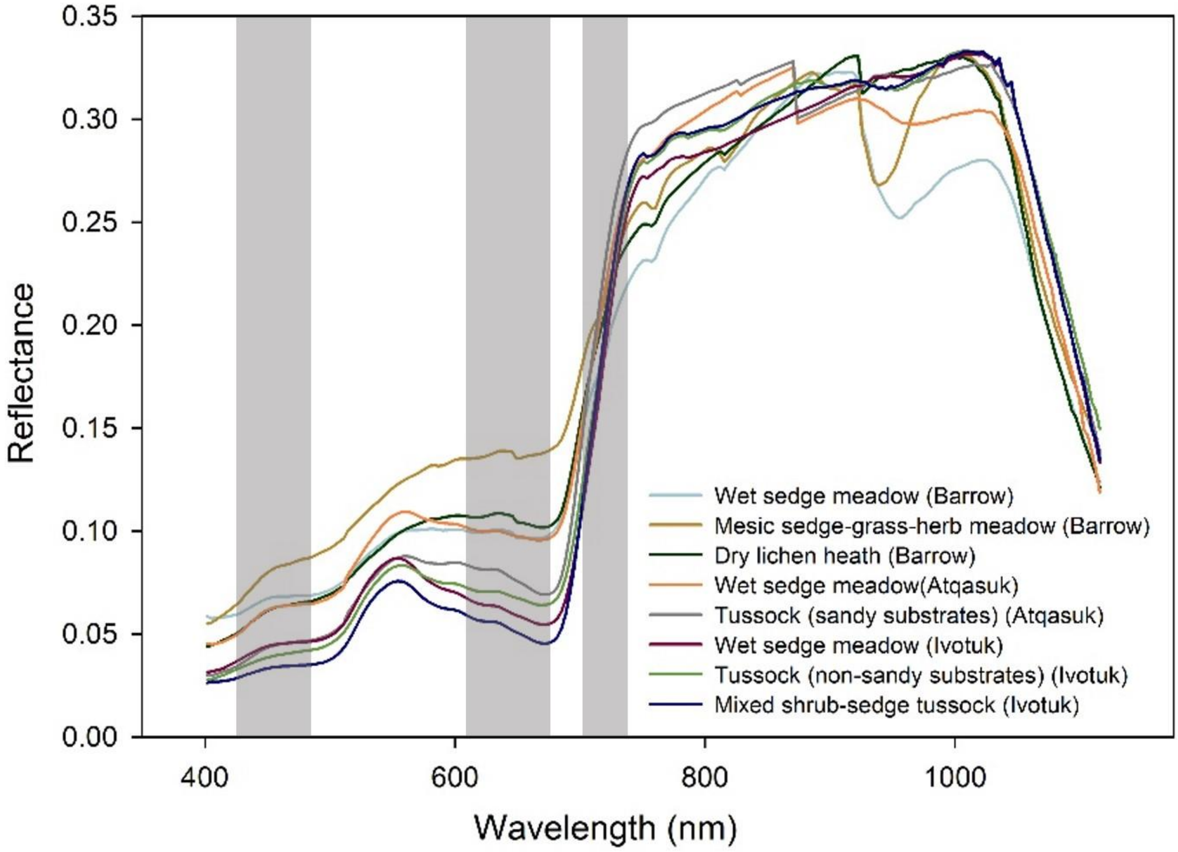


Figure 4. Mean spectral profile for each vegetation community. Vertical grey boxes indicate the statistically significant different regions ($P < 0.0001$) between each community type.

Principal Component Analysis: The PCA showed that communities were separable across all four field sites (Figure 5). However, Atqasuk showed better separation than the other sites. For Barrow-BEO/Barrow-BES (Figure 5a), 93.3% of the variation in the dataset is explained by the first component alone, and 99.7% is explained by the first two components. For Ivotuk, 67.9% of the variation is explained by the first component and 86.5% is explained by the first two components. Finally, for Atqasuk, 74.9% and 94.8% of the variation is explained by the first component and the first two components respectively.

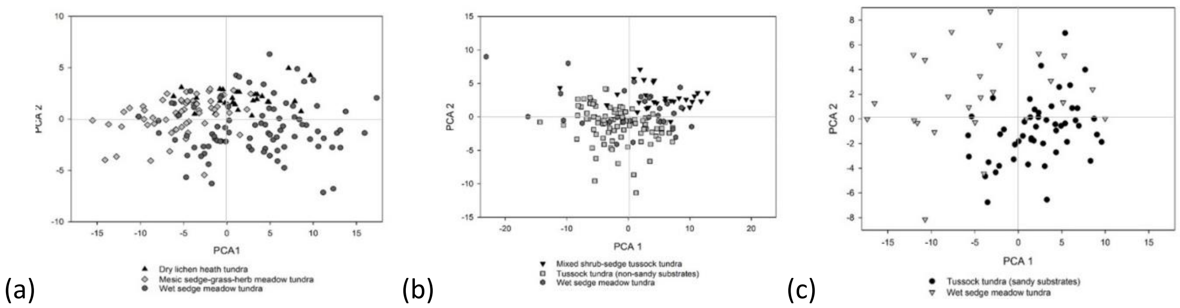


Figure 5. Principal component analysis of UniSpec data using combination of blue, red and red edge regions of spectrum for (a) Barrow, (b) Ivotuk, and (c) Atqasuk.

Linear Discriminant Analysis: The LDA analysis was extremely successful in predicting vegetation communities using the rescaled field spectroscopy data (UniSpec$_{WV2}$) at each field site (Figure 6). Classification accuracy for each community type at Barrow (Figure 6a) were 90% (mesic sedge-grass-herb meadow), 96% (dry lichen heath) and 98% (wet sedge meadow) with a Kappa coefficient of 0.92. Adding vegetation indices (NDVI, NDWI and EVI) further improved vegetation classification accuracy, with 92%, 100% and 99% accuracy, respectively (Kappa coefficient: 0.94).

The LDA analysis was less successful using the data extracted from the WorldView2 image itself, with classification accuracies of 53% (mesic sedge-grass-herb meadow), 61% (dry lichen heath) and 43% (wet sedge meadow) (Kappa coefficient: 0.24) , with slight improvement when adding vegetation indices (Kappa coefficient: 0.26).

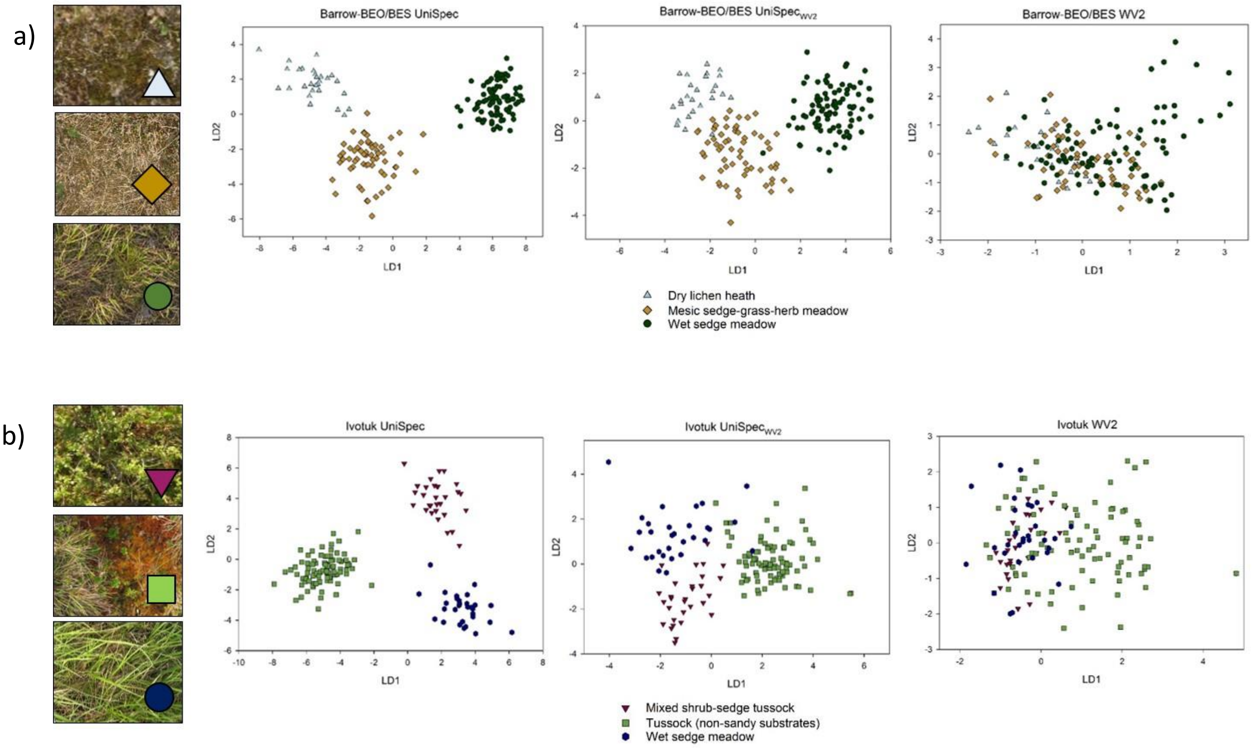


Figure 6. Linear discriminant analysis (LDA) results for a) Barrow-BEO/BES and b) Ivotuk (Atqasuk contained only 2 vegetation communities therefore a plot could not be created). UniSpec data represents field spectroscopy spectral data, $UniSpec_{WV2}$ data represents field spectroscopy data rescaled to match bands of the WorldView2 imagery, and WV2 represents data extracted from the WorldView2 imagery.

The LDA analysis was also successful in predicting vegetation communities at Ivotuk using the rescaled field spectroscopy data (Figure 6b). Classification accuracy for each community type were 83% (wet sedge meadow), 90% (mixed shrub-sedge tussock tundra) and 96% (tussock tundra (non-sandy substrates), with a Kappa coefficient of 0.86, which was further improved with additional vegetation indices (90%, 97% and 9&% respectively, Kappa coefficient: 0.93). Similar to Barrow, the LDA did not perform as well using the extracted data, with classification accuracies of 50% (wet sedge meadow), 59% (mixed shrub-sedge tussock tundra) and 64% (tussock tundra (non-sandy substrates) with a Kappa coefficient of 0.37. A small improvement occurred from inclusion of vegetation indices (53%, 55% and 67% respectively, Kappa coefficient: 0.4).

Finally, classification accuracies for each community type at Atqasuk using the rescaled field spectroscopy data were 92% (tussock tundra (sandy substrates)) and 96% (wet sedge meadow) with a Kappa coefficient of 0.88. This was further improved once again with the inclusion of vegetation indices (96% and 98% respectively, Kappa coefficient: 0.94). Unlike Barrow and Ivotuk, the LDA analysis using the extracted image data was successful, with a classification accuracy of 86% (tussock tundra (sandy substrates)) and 92% (wet sedge meadow) with a kappa coefficient of 0.74, with a slight decline in accuracy with inclusion of vegetation indices (86% and 88% respectively, Kappa coefficient: 0.71).

Mapping vegetation communities: The three different techniques used in mapping vegetation resulted in similar maps, but with certain localized differences. For example in Figure 7 I show the expert knowledge and the k-mean vegetation maps. The expert knowledge maps at Barrow-BEO and Barrow-BES have a more localized distribution of the dry lichen heath communities, whereas the k-means technique gives a much more widespread distribution. This could be due to in the field, the dry lichen and mesic-sedge-grass-herb meadow communities' looking similar to the eye, where as their spectral profile is different enough to warrant a separation using the unsupervised classification. This is shown also in the LDA analysis (Figure 6a) where the two communities are separated successfully. On the other hand, both the expert knowledge and the k-means mapping technique both show similar distribution of wet sedge meadow communities.

The difference between both techniques is also apparent at Ivotuk. It is impossible to differentiate between tussock tundra and mixed shrub-sedge tussock tundra using the expert knowledge technique due to the high level of heterogeneity found here, with the transition zones between both community types being extremely fuzzy. However, the k-means map does pick up the difference between the two communities, and once again the LDA analysis does show the separability also (Figure 6b).

In Figure 8, the spatial output of the field spectroscopy LDA classification for Barrow-BEO and Barrow-BES once again shows a similar distribution of wet sedge communities and mesic sedge-grass-herb meadow communities.

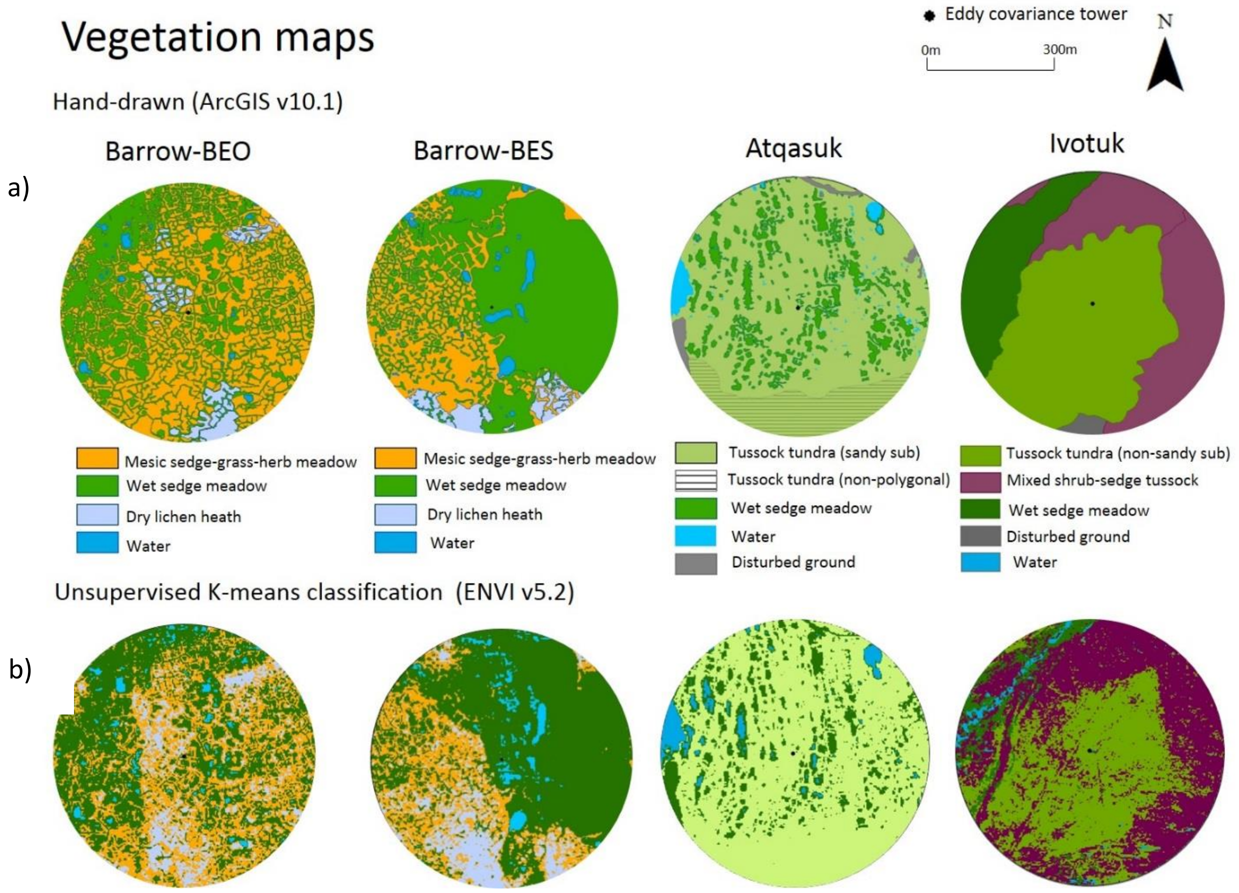


Figure 7. a) Expert knowledge and b) unsupervised k-means classification vegetation maps for Barrow-BEO/BES, Atqasuk and Ivotuk. Disturbed ground is defined as either road or areas where the natural vegetation has been impacted by human use.

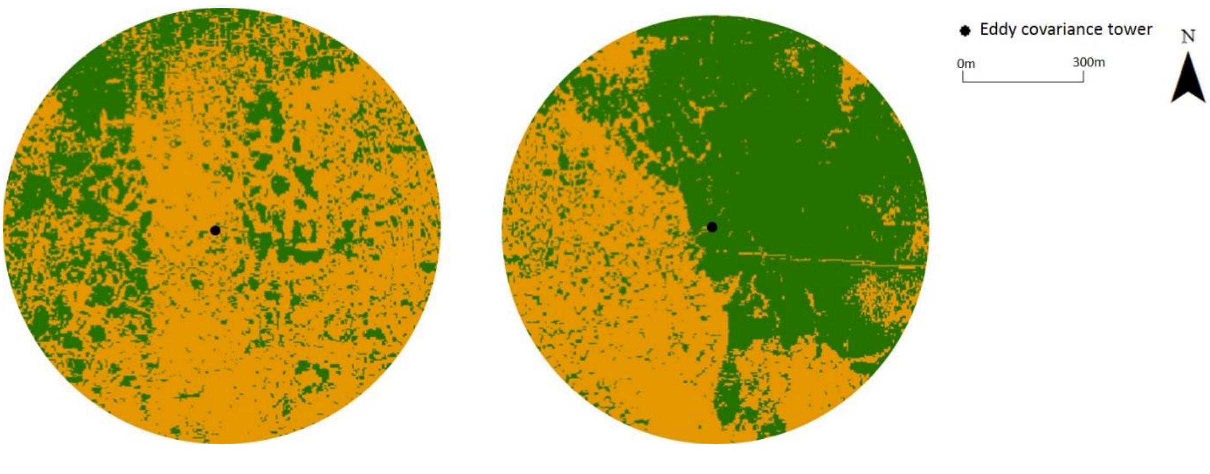


Figure 8. Field spectroscopy vegetation map for Barrow-BEO and Barrow-BES. Wet sedge meadow distribution is indicated in dark green

Future collaboration with the host institution (if applicable);

Maximum 0.5 page

We will continue our collaboration by finishing up the analyses and writing up the results as two scientific papers, which will be part of Scott J. Davidson's dissertation

Foreseen publications/articles resulting from the STSM (if applicable);

Davidson, S.J., M.J. Santos, V.L. Sloan, J. Watts, G. K. Phoenix, W. C. Oechel and D. Zona. (*In preparation*). Remote sensing analysis of arctic tundra vegetation communities. *Remote Sensing*

Davidson, S.J., M.J. Santos, V.L. Sloan, J. Watts, G. K. Phoenix, Reuss-Schmidt, K., W. C. Oechel and D. Zona. (*In preparation*). Using remote sensing for vegetation-mediated upscaling of CH_4 fluxes in arctic tundra ecosystems. *Biogeosciences*

Other comments (if any).

Confirmation by the host institution of the successful execution of the STSM;

(it might be separate document written and signed by the Host - confirmation of acceptance from a senior Researcher affiliated to the Host institution formally accepting the scientific report.)

URGENT:

- The grantee is required to submit a short scientific report to the host institution (for information) and OPTIMISE Secretariat (optimise@aber.ac.uk) and STSM coordinator: radoslaw.juszczak@up.poznan.pl for approval within 30 days after the end date of the STSM.
- The failure to submit the scientific report within 30 days will effectively cancel the grant;
- The MC Chair (or the STSM coordinator) is responsible for approving the scientific report and informing the Grant Holder that the STSM has been successfully accomplished;
- After receipt of the approval by email, the Grant Holder will execute the payment of the grant.