EVALUATION OF AVHRR NDVI FOR MONITORING INTRA-ANNUAL AND INTERANNUAL VEGETATION DYNAMICS IN A CLOUDY ENVIRONMENT (SCOTLAND, UK)

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ABSTRACT:

Vegetation change detection has become increasingly important in understanding vegetation dynamics and its role in terrestrial and atmospheric systems. In the case of Scotland, there is a need to routinely monitor habitats which include native pine woodland, montane habitats, upland heathland and blanket bog (EC Habitats Directive). In northern temperate regions restricted and distinct growing seasons impart significant phenological changes in vegetation which are detectable in remotely sensed data. However, the high frequency of cloud cover in northern temperate climates presents a complicating factor in the use of remote sensing data for monitoring vegetation. High cloud probability means loss of data which makes it more difficult to compile and interpret time-series of data than would be the case in less cloudy areas. For this study satellite data of coarse spatial resolution and high temporal frequency from the NOAA/AVHRR sensor have been evaluated for their utility in monitoring interannual and intra-annual vegetation dynamics of semi-natural and agricultural vegetation types in Scotland. Weekly composited NDVI images for 1995 to 1998 were used in conjunction with digital maps of vegetation distribution to extract NDVI time-series. Temporal development curves of the NDVI values for various vegetation cover types were visually compared to observe the phenology and to detect changes in NDVI response between years. The weekly time-series approach proved to be useful for understanding seasonal dynamics and allowed for interannual comparisons despite the high cloud-cover rate. However, it has also become evident that pre-processing and accurate calibration of the AVHRR imagery is extremely important.

1. INTRODUCTION

Since the 1970s it has been possible to receive radiometric data from meteorological and Earth resources satellites that allow us to analyse the interactions between the solar radiation spectrum and ocean, atmosphere and land properties. In particular, the high temporal resolution sensor Advanced Very High Resolution Radiometer (AVHRR) of the meteorological satellite series TIROS-NOAA (National Oceanic and Atmospheric Administration) has been used to gain knowledge of the temporal, spatial and reflective behaviour of vegetation. The daily coverage that this series of satellites and sensors has provided offers a unique and long-term dataset with which to investigate the magnitude of changes in vegetation at continental and global scales (Lambin, Ehrlich 1997; Malingreau, 1986).

Vegetation change detection has become increasingly important because of the current interest in the establishment of human impacts upon the environment. Long-term monitoring programmes have been developed to examine and monitor these changes. Conservation bodies like Scottish Natural Heritage (SNH) are required by national and European legislation to routinely monitor important and protected habitats. In the case of Scotland, these habitats include native pine woodland, montane habitats, upland heathland and blanket bog, each recognised by the EC Habitats Directive (ECNC, 1992; MLURI, 1998). Information on the phenology and dynamics of vegetation types and the magnitude and speed of their possible changes needs to be provided to these conservation agencies.

Remote sensing could play an important role in identifying areas of change at large scales. However, in north temperate climates restricted and distinct growing seasons impart significant phenological change in vegetation, the magnitude and pattern of which needs to be understood in order that the more important longer-term interannual changes can be properly identified and understood.

This study is based on weekly NDVI data of the AVHRR sensor over Scotland from 1995 to 1998. It aims to investigate and assess the use of this imagery for monitoring the phenology of semi-natural vegetation in an environment with a high cloud cover rate. Most studies, especially early on, have focussed on monitoring and mapping of African, South-American or Asian vegetation communities, mostly using monthly composited NDVI data or single images (Malingreau, 1986; Lambin, Ehrlich, 1997). Several studies analysed time-series satellite data in order to develop intra-annual (DeFries et al., 1995) and inter-annual (Reed et al. 1994) profiles of the condition of vegetation. Few studies have dealt with regional monitoring of vegetation dynamics in a northern temperate climate using short-term time-series of AVHRR NDVI data. The monitoring of vegetation with a continuous time-series of weekly NDVI in such a climatic environment will be made difficult by the frequent presence of clouds and haze. To minimise this problem, the composited period can be augmented, e.g. monthly or biweekly. However, this will also mean a loss of information that is required when looking at vegetation types with high seasonality.

2. DATA

2.1 Satellite data

Weekly composited NDVI images of the NOAA AVHRR sensor over 4 years (1995-1998) were taken to observe the dynamics of certain vegetation types in Scotland. The NDVI data for this study were derived from the *German Remote Sensing Data Centre* (DFD). At the DFD, the data were radiometrically calibrated and geometrically rectified. A couple of cloud/water tests were performed to ensure that only NDVI-values over cloud-free land surfaces were derived. Daily maps were composed on the maximum NDVI value basis at every pixel's position. The weekly composites were calculated from the daily maximum NDVI values at every pixel's position.
No atmospheric corrections were performed on the data. However, there is some evidence to suggest that atmospheric influences are attenuated to a certain degree through the calculation of the NDVI (Mather, 1999). This means that it is very likely that all NDVI values in the images used are lower than with atmospheric correction. As this is a qualitative study and as only images from the same sensor and the same pre-processing chain are compared with each other, qualitative analysis can be done. What can be observed is the dynamics of the vegetation and the trend between years.

2.2 Vegetation Dataset

Data on the distribution and state of semi-natural vegetation was acquired from *Scottish Natural Heritage* (SNH) who provided the Land Cover of Scotland 1988 dataset and *Highland Birchwoods* who provided the Scottish Semi-Natural Woodland Inventory.

2.2.1 The LCS88 dataset: The Land Cover of Scotland 1988 (LCS88) survey was the first ever national census of land cover in Scotland produced by the *Macaulay Land Use Research Institute* on behalf of *The Scottish Office.* It contains land cover information in digital format in the scale of 1:25 000.

In the LCS88 data set the total area for Scotland is 78 828 km^2. Of this, over 50% is covered by semi-natural ground vegetation, with heather moorland (8.7%) and peatland (8.4%) as the largest single features. Heather moorland and peatland in mosaics represent a further 22.3% of the total land area. Woodland accounts for a total of 14.7% (mainly in plantations). The agricultural cover types arable (11.2%) and improved grassland (13.0%) are the most extensive single features. Semi-natural vegetation is the most extensive vegetation feature covering more than 60% of Scotland. The vegetation is usually less than 0.75 m in height and has not been subject to reseeding or other major improvement.

2.2.2 The Scottish Semi-Natural Woodland Inventory: This inventory was compiled by *Highland Birchwoods Ltd.* on behalf of the *Caledonian Partnership* and the *Millennium Forest for Scotland Trust*. The following types of woodland have been used for this study: Planted coniferous forest with a closed canopy, semi-natural broadleaf (degraded or fragmented), semi-natural conifer (degraded or fragmented), mixed broadleaf and conifer, as well as mainly conifer, both with different stages of naturalness and canopy closure.

3. METHODOLOGY

3.1 Selection of the landcover areas

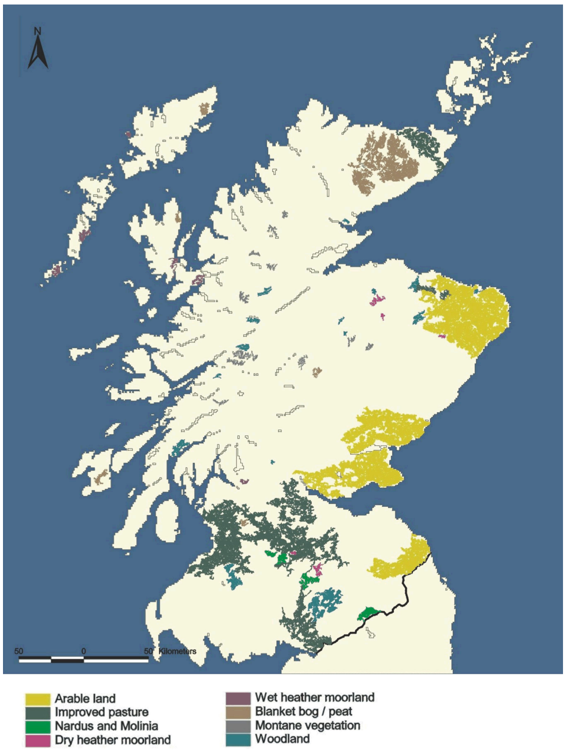
Land cover types and areas of the SNH and Highland Birchwoods Ltd. data sets were selected using ArcView 3.0a.
The criteria were:

- The land cover types have to be representative for Scotland.
- The size of the areas should exceed 400 ha, corresponding to at least 16 pixel (4 km²) on the satellite pictures to minimise border effects.
- Compactness: Ideally, the polygons should be as round as possible which assured the smallest amount of borderline pixels.

The following land cover types were chosen (see table 1 and figure 1): Heather moorland and peatland, as they account for the greatest ground coverage of semi-natural vegetation in Scotland; montane vegetation, as representative of the montane zone of the Highlands, and semi-natural grassland in the form of *Nardus stricta* and *Molinia caerulea* ground cover. To compare these semi-natural cover types with anthropogenic ones, representative areas of improved pasture and arable land were also taken into account.

PRINCIPAL FEATURES	MAJOR FEATURES	MAIN FEATURES
Semi-natural ground vegetation	Heather moorland	**Dry heather moorland**
		Wet heather moorland
	Peatland	**Blanket bog / peat**
	Grassland	***Nardus / Molinia***
	Montane	**Montane vegetation**
Agricultural land	Agricultural land	**Improved pasture**
		Arable land
Woodland	Coniferous forest	**Plantation, full canopy cover**
		Mainly coniferous forest
		Semi-natural coniferous forest
	Broadleaf forest	**Broadleaf forest**

Table 1: Selected land cover types (indicated by bold letters)



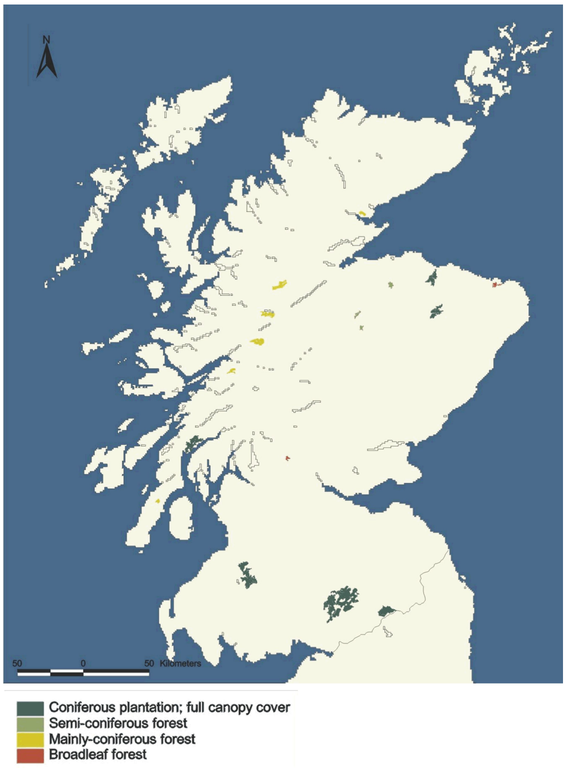


Figure 1: Location of the selected land cover polygons across Scotland

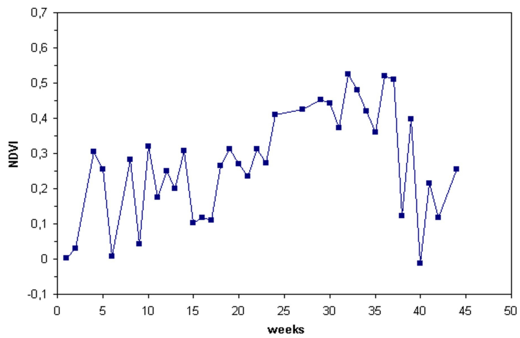
3.2 Creation of areas of interest in the NDVI dataset

After the selection of the relevant land cover data, those polygons were overlaid with the NDVI data and 'cut out' on the NDVI images. Areas of interest (AOI) were thereby created, one for each land cover type. A programme using Erdas Macro Language (EML) was developed, that, using the AOIs, removed cloud and boundary pixels and, from the remaining pixels, calculated the average NDVI for each area. Finally, the extracted NDVI data were exported and displayed. The results were thus the weekly NDVI values for the years 1995-98 for every land cover polygon selected.

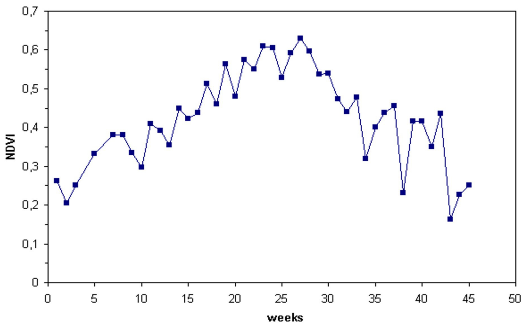
3.3 Further processing steps

The results were displayed using a spreadsheet-programme. Graphs were made for all polygons. The results were displayed in such a way as to give an overview of changes between the polygons of each vegetation type and changes over time for any polygon.

When looking at individual NDVI curves of a single polygon, it can be seen that the curves are noisy (figure 2). The main reason for this may be that pixels with apparent low NDVI values contain sub-pixel elements of clouds or cloud shadow. Clouds in a pixel diminish NDVI values. Highly variant atmospheric effects (water vapour absorption and aerosol scattering) might also be responsible as no atmospheric correction was applied in the pre-processing. Another reason might be that the calculation of the mean NDVI for a polygon would be undertaken, even when there was only a few cloud-free pixels in the polygon. The possibility of getting a representative NDVI value for this polygon on this date is thus low. Pixels with small clouds are therefore highly weighted. This is even more so where polygons are made up of a smaller number of pixels.



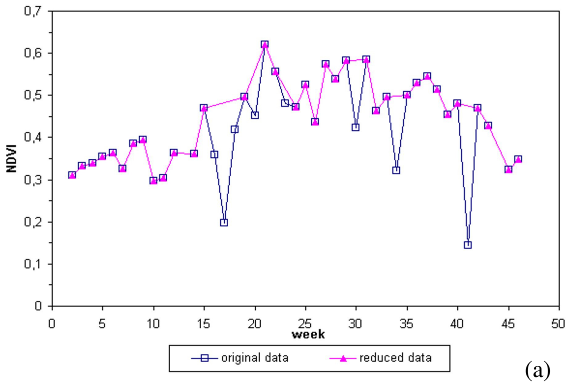
(a)



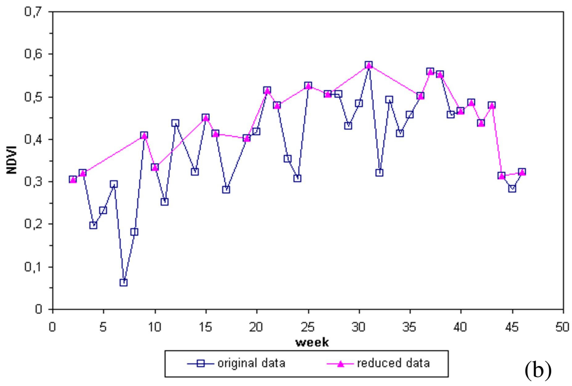
(b)

Figure 2: Mean NDVI of different polygons of wet heather moorland (a) and arable land (b).

It was thus decided to only include weeks in further interpretation whose average NDVI had been calculated with as many pixels as possible. The remaining pixels, however, should still display a meaningful curve. For some polygons it was possible to refer to the maximum number of pixels in a polygon, otherwise a limit was set individually to include all weeks where the pixels used for the calculation consisted of more than half the total pixel amount. As can be seen by using this technique, the probability for representative data was increased and the curves could be flattened. Figure 3 shows two cover types before and after the setting of the limit: the smoothing effect can be seen well in the graphs of coniferous forest plantation (a) and dry heather moorland (b).



(a)



(b)

Figure 3: Polygons of coniferous forest plantation (a) and dry heather moorland (b) before and after the selection of weeks.

3.4 Filtering of the dataset

Filtering is a common technique for smoothing NDVI data. Usually, either a weighted or unweighted moving average filter or a median filter is used, sometimes both are combined (Duchemin, 1999; Reed et al., 1994; Malingreau, 1986).

The moving average formula is based on the average value of the variable over a specific number of preceding periods, e.g. 3 or 5. The moving average of 3, for example, is calculated using the running NDVI and the values just before and after in the time series.

After experimenting with a weighted moving average filter (weighting coefficient of 0.25, 0.5, 0.25), median filtering, and moving average filters of 3 and 5 points, an interval of 5 composite periods was finally selected for all cover types except for pasture and arable land which were filtered with a 3 point filter. It was discovered that a 5 point filter would smooth out too many peaks and troughs in these cover types, so that the overall trend was more difficult to establish. Figure 4 gives an example (wet heather moorland 1996) of how the data were smoothed, starting with the original data which is noisiest; the reduced average, i.e. only pixels above a certain limit had been included in the calculation, shows clearly that most troughs are flattened. It can be seen that all the filtered curves are much smoother. As a comparison the moving average of 5 points of the original unsmoothed data is given. It is by about 0.01 to 0.04 units lower than the moving average of the curve with the pixel limit.

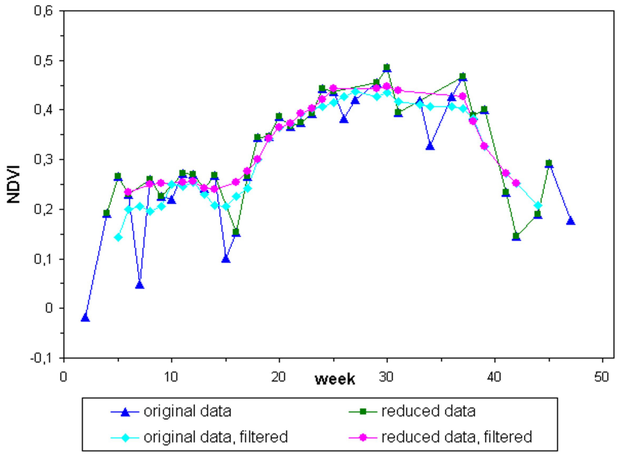


Figure 4: Filtering of the dataset (wet heather moorland 1996, polygon 3): Original weekly composites, reduced data and smoothed data (moving average filter of 5).

4. RESULTS

It was apparent that the original data curves of the NDVI are very noisy. Sub-pixel clouds, cloud shadow, atmospheric effects and the small number of polygons used in certain cover types might all be factors that lead to the noisiness of the curves. The missing **atmospheric correction** also means that the NDVI values are lower as if correction had been undertaken.

The **cloudiness** of the images also results in a limitation of the data that is available in each year. It can be observed that only values for the weeks around 5–50 exist which means that Scotland is extremely cloud-covered during the winter months. Through the necessary smoothing of the curves, weeks were eliminated so that effectively NDVI data can only be displayed for roughly weeks 8-45. A look at climate graphs validates that the months with the highest precipitation are November to February. This, along with the low sunshine duration, implies a high cloud probability. As photosynthetic activity is low during this time and the winter months are therefore less interesting in vegetation studies, the NDVI observations allow for an interpretation of the most interesting part of the vegetation cycle. Interpretation of some forest polygons is made difficult, especially of semi-natural and mainly coniferous forest because of limited data availability due mainly to cloud cover problems.

4.1 Intra-annual variations of the NDVI of different vegetation types

The **individual polygons** of each vegetation type cover different areas of Scotland. It was investigated whether differences in the behaviour of the NDVI curve in the polygons of each cover type were apparent. This is of interest for looking at the advance of the 'green wave', the start of the growing period. Differences are to be expected; depending on the vegetation type, in the Highlands and Islands of Scotland the green-up is likely to start later than in the Lowlands. In the graphs, those differences are only existent to a minor extent and could therefore not be detected with the coarse resolution of this imagery (see figure 5). The problem is that apparently the time differences in the beginning of the growing season in each vegetation type take place within a few days. If all those days fall within the compositing time of the NDVI week, then they are masked out. Differences in NDVI between the years for each cover type polygon, however, do exist for the magnitude of the NDVI in the order of around 0.05 to 0.1, but differences in the timing of the growing season do not appear to be evident.

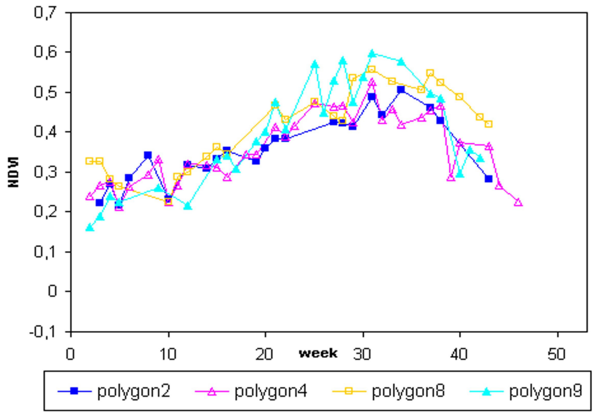


Figure 5: NDVI curve of blanket bog polygons, 1997. The polygons are numbered (from NW to SE). The lower the number the further north is the polygon.

4.2 Inter-annual comparison of cover types

4.2.1 Comparison between different cover types:

However, despite limitations in data availability and unexplained phenomena, the **dynamics of the vegetation response** can be seen well within the NDVI dataset. Inter-annual comparisons of the NDVI curves can be made. Figure 6 shows the NDVI curves for selected cover types exemplary in the years 1996 and 1997. The curves are displayed in a nearly consistent order each year: the highest values always occur for pasture and arable lands which lie around 0.6 units or more. This is closely followed by broadleaf forest and *Nardus/Molinia* (0.5-0.6). These vegetation types display a high seasonal response with a large NDVI magnitude and range. For arable land, pasture and broadleaf forest, the onset of the growing season in spring leads to an abrupt green-up, which can be seen in the steeply ascending curves. A high NDVI range can also be seen for montane vegetation, especially in 1995, 1996 and 1998. However, this is also the cover type where the peak in the growing season, and the start of it, have the lowest NDVI values. Montane polygons will consist of mixed pixels as this class is distinguished by the distribution of the vegetation types in the higher elevation montane mountain areas rather than by the distribution of specific vegetation types themselves. This class can also be expected to contain responses from rock outcrops and soil because vegetation above a certain altitude in the mountains will be sparser. This would explain the low NDVI values found. The steep ascent of the curve might be due to the fact that the sensor response until spring is that of rocks, soils and potentially snow (= low NDVI). As soon as the first plants emerge the NDVI will rise abruptly.

Blanket bog/peat and wet heather display similar NDVI curves in magnitude and dynamics (figure 6, figure 7b). This represents either a real NDVI response that is similar for both cover types or is enhanced by the fact that those cover types co-occur in the same ecosystem. SNH states that these covers mostly occur in mosaic classes, i.e. mixed in the same area. Along with dry heather which has slightly higher NDVI values, they experience NDVI values of around 0.4-0.55 in summer (compare figure 7). Their curves are flatter than those of arable land, pasture and broadleaf forest and have some of the longest peaks of all cover types, i.e. a long growing season.

The strength of the NDVI to distinguish vegetation at community level is demonstrated by the response of wet and dry heather which each display characteristic features.

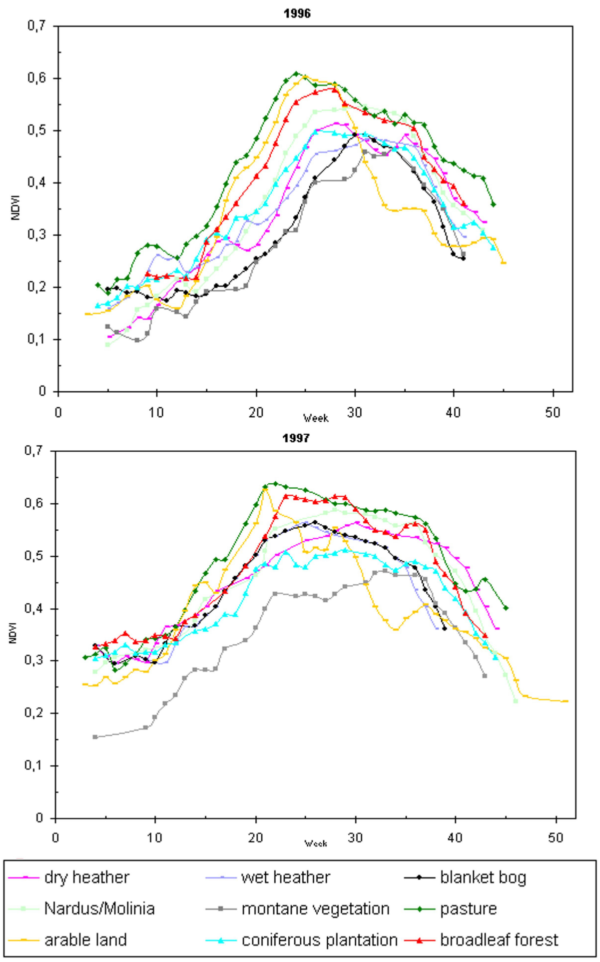


Figure 6: Comparison of cover types 1996 and 1997

Another interesting feature that is worth comparison between cover types, is the **growing period**. To establish the start of the growing season is difficult. For example Lloyd, 1990 assigned a threshold NDVI (0.099) at which the vegetative activity is assumed to begin. This threshold, however, varies with vegetation type, soil background, illumination condition, sensor and calibration. A single threshold is therefore not of much use. A sudden increase of the curve as a signal of the onset of significant photosynthetic activity might be more useful. Pasture and arable land have a steep increase in NDVI from the mid/end of March onwards (see figure 6, graph of 1997). They reach their peaks at the same time, around week 21. The curve then falls slowly for pasture and abruptly for arable land with a deep trough in the curve around week 35 that reveals the harvest. Wet heather, dry heather, *Nardus/Molinia* and blanket bog begin to rise with a delay of about 2 weeks (between weeks 14 and 18). The rise is also more gradual with nearly level NDVI values in summer. The rise of montane vegetation starts latest

(around week 19), perhaps due to lower temperatures in these higher elevation areas. An abrupt decline of NDVI sets in between weeks 36 and 39 for all cover types except arable land (around week 22-27) and pasture in years 1995 and 1998 (week 28/29).
It is apparent that each vegetation type shows a characteristic NDVI curve.

4.2.2 Comparison between years in each cover type: By comparing the summarised polygons of each vegetation cover with each other, it can generally be said that the year 1995 in all the cover types is the one with the lowest NDVI, generally around 0.1 lower, which is most apparent in the summer. Figure 7 shows exemplary the time-series of 1995 to 1998 for forest cover types (a) and Highland vegetation (b). There is also a consistent order to be seen in the magnitude of the NDVI curves, especially in summer and spring which has been described above for different cover types. 1997 and 1998 have similar and always the highest NDVI values compared to 1995 and 1996. 1996 has, like 1995, low spring values but rises sharply to nearly reach the magnitude of the 1997 and 1998 NDVI response. This is therefore a trend that can be seen in all cover types.

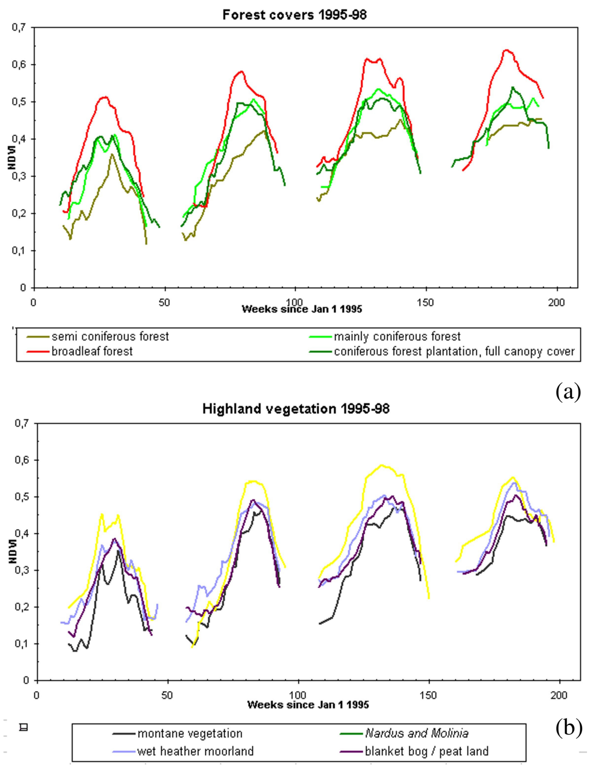


Figure 7: Time-series (1995-1998) of forest covers (a) and Highland vegetation (b)

5. CONCLUSION

This project has shown the utility of 1.1 km AVHRR NDVI data to monitor vegetation dynamics in a northern temperate climate using Scotland as an example. The probability of cloud covered imagery is high in these high latitudes which means limited datasets. Despite these cloud cover problems it is still possible to derive meaningful NDVI curves that allow for the detection of change in vegetation.

It has been demonstrated that the time-series approach over several years is useful for understanding seasonal dynamics of different vegetation types, as well as allowing inter-annual comparisons of cover types. By taking a continuous series of images with a short compositing period of one week, the NDVI curves of a cover type between years can be observed in detail. This method of change detection is straightforward and consumes comparatively little computational time. Vegetation can be monitored continuously and, over a longer time period, changes can be followed.

However, it has also become evident that pre-processing and accurate calibration of the AVHRR imagery is extremely important. Because of different calibration coefficients used in 1995 compared to years 1996 to 1998, care has to be taken when comparing that year to the others in terms of NDVI magnitude.

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