Vegetation Change Detection for Mapping the Effects of Global Climatic Change:
A Test Case in Northern Finland using Satellite Remote Sensing

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Abstract

It has been predicted that some boreal tree species would migrate north several hundred meters per year to coincide with the predicted global warming due to doubling CO₂ by the middle of next century. It has been said that large parts of the boreal forest and tundra will migrate and disappear because of global warming. Twenty years have passed since the Landsat 1 launching and the average global temperature has shown a tendency to increase over these two decades. The basic concepts of monitoring vegetation shifts using satellite data are described in this paper. A system for the detection of vegetation shifts was tested in northern Finland using Landsat data, however, no clear evidence of shifts was observed.

Key words: global warming, boreal forest, tundra, monitoring, remote sensing

1. Introduction

It has been pointed out that global climatic change will cause drastic changes in vegetation, especially in high latitudinal areas. Simulations using various general circulation models have predicted that the annual average global temperature will increase by from 1.5 to 4.5°C by between 2030 and 2050. Temperature increases in winter in the high latitudes may constitute the greatest change on Earth and the length of vegetation growing seasons will become longer (Boer et.al., 1990, Singh and Wheaton, 1991). A temperature change of 3°C would be equivalent to a 250km shift in latitude or a 500m elevation shift (Gates, 1990). In other words, boreal species would have to migrate about 6 km per year to stay within their ideal habitat. Also, these temperature increases would accelerate vegetation growth. According to those simulation results, it is predicted that global vegetation will suffer from global warming, especially in the high latitudes and arid areas (Boer et.al., 1991, Emanuel et.al., 1985, Gates, 1990, Singh and Wheaton, 1990).

Various effects on boreal and tundra vegetation brought on by global warming have been predicted. For example, a pollen study has revealed that boreal coniferous species seem to have migrated a few hundred meters per year following the glacial retreat in North America (Overpeck et.al., 1991) and potential migrations under CO₂ doubling scenarios have been estimated to be up to several hundred meters a year (Gates, 1990, Singh and Wheaton 1991). Since the global temperature would increase too quickly based on these CO₂ doubling scenarios, large parts of the boreal forests will be replaced by cold temperate forests and disappear (Emanuel et.al., 1985). Warmer and drier summers will cause more frequent forest fires, forest declines and permafrost melt (Shugart 1992) which might produce bogs (Boer et.al., 1990). A milder climate might also accelerate forest growth (Boer et.al., 1990).

Among these effects, vegetation boundary shifts are most likely to be detected using satellite data. Therefore techniques to monitor the boundary shifts were developed and tested using Landsat Multispectral Scanner (MSS) data. A test site was selected in a succession zone between the boreal forest and the Arctic tundra in Finland. Basic ideas, problems and the possibility of monitoring vegetation changes caused by global warming are reported in this paper.

2. Test Site and Data

A test site was selected in northern Finland for this study. A part of this site (Kevo, around 69° 30'N 27° 00'E) is a very strict nature conservation area making it ideal for monitoring vegetation which has not been directly disturbed by

humans. The test site extends over forest-tundra and shrub tundra zones. A thirteen-degree isotherm of July average temperature, which represents the northern limit of present boreal forests (Singh and Wheaton, 1991), runs through the middle of the test site. The main vegetation here are shrub tundra, dwarf birch (*Betula* spp.) forests and birch-pine (*Pinus sylvestris*) forests. The topography in this area is gentle and there are numerous lakes. Rocks are exposed at the tops of hills (National Board of Survey, 1988). However, temperature in Finland seems not to change significantly during these three decades (Heino, 1992).

Two Landsat MSS images taken on September 1, 1972 and July 18, 1987 were used in this study. Both images, which covered areas 90 km (east to west) and 110 km (north to south), were stored in a hard disk of a Sun Sparc II computer, then coregistered and processed using an image processing system 'ERDAS'.

3. Basic Concepts of Vegetation Monitoring

The followings are assumed for changes in vegetation cover due to global warming: a) Vegetation boundaries will shift due to forecasted global warming. b) In northern Finland, temperature is the most important growth factor. Thus, boundary shifts would be particularly apparent between the boreal forests and shrub tundra. c) Boreal pioneer species will invade to the shrub tundra first.

The changes in the vegetation cover are assumed to cause the following spectral changes: d) Spectral reflectance in the near infrared region will increase when the biomass increases in sparsely vegetated areas. e) Since the normalized vegetation index $(NDVI, (Ch4(MSS) - Ch2(MSS)) / (Ch4(MSS) + Ch2(MSS)))$ is sensitive to the biomass which ranges less than 3 in the leaf area index (LAI) (Asrar et.al., 1989), biomass increase in sparsely vegetated areas should be well detected using the NDVI. f) The invasion of boreal pioneer species, especially birches, should increase the values of the NDVI in the transition zone. Schematic figures of the expected changes are shown in Figure 1.

The long term boundary shift of the vegetation boundary would be an indicator of the changing atmosphere. A short term - two or three decades - local shift does not necessarily indicate atmospheric change but only changes in the weather conditions (Shugart et.al., 1992). If the boundaries were monitored on a global scale for the long term, distances of the shifts could be mapped and evaluated to understand the tendency of vegetation changes.

4. Method

At first, intensities of the 1972 MSS signals were adjusted to those of the 1987 MSS signals using the average digital numbers (DN) of a dark water area (DN 11.9 (ch2), 1.3 (ch4) for 1972, 16.8 (ch2), 10.0 (ch4) for 1987) and a bright rock area (DN 40.6 (ch2), 32.7 (ch4) for 1972, 48.0 (ch2), 48.0 (ch4) for 1987) as standards, because they were common in both images and are supposed to be spectrally invariant. Then the NDVI of the two MSS images were derived from radiance values which were calculated as follows.

Matching of the intensities:

$$DN72'(i, CHj) = (DN72(i, CHj) - Water72(CHj)) * \frac{(Rock87(CHj) - Water87(CHj))}{(Rock72(CHj) - Water72(CHj))} + Water87(CHj) \quad (1)$$

Computing of the radiance:

$$Radiance(i, CHj) = (DN(i, CHj) - Water87(i, CHj)) * Gain87(CHj) \quad (2)$$

where

DN72(i, CHj)	is the registered intensity for pixel i in channel j by the MSS sensor in the 1972 data
DN'72(i, CHj)	computed 1972 MSS DN adjusted to the 1987 MSS DN
DN(i, CHj)	DN72'(i, CHj) and DN87(i, CHj)
Water72(CHj), Water87(CHj)	the mean intensity of dark water
Rock72(CHj), Rock87(CHj)	the mean intensity of bright rock

Radiance(i,CHj)	computed radiance (mW/cm ² /sr/um) (RESTEC, 1986)
Gain87(CHj)	gain of Landsat 5 MSS: 0.0660/DN(Ch2), 0.0615/DN(Ch4)

The 1972 NDVI was subtracted from the 1987 NDVI and the intensity changes were visually observed using a color coded NDVI difference image (Fig 2). Then differences of their edges and peaks in the profiles of the NDVI were examined.

5. Results and Discussion

Water and rock are very often used as pseudo-invariant standards of spectral calibration. Though it could not be guaranteed that the intensity adjustment standards, i.e. a lake and a rock, did not have any true spectral change, the NDVI values of two images agreed very well. This intensity matching seemed good enough for comparing vegetation boundaries in the two NDVI data.

The NDVI difference image (Fig. 2) showed regional changes in the NDVI. Since the variance of the NDVI difference was quite large, the difference image was smoothed using an average filter of 5 by 5 pixels to make general tendencies more clear.

The NDVI had its greatest increases in the mountain birch communities (Fig. 3) along rivers, and the NDVI generally decreased in rocky areas. Since two MSS images had been derived in different seasons, the NDVI difference should somewhat reflect seasonal vegetation changes. The seasonal factor made it difficult to interpret the NDVI difference. This interfered with the determination of any other causes which contributed to the NDVI changes.

Since the profiles made peak positions and edges of the NDVI clear, this method would be effective for boundary shift detection. However, only few shifts up to about 200 m were identified in the test site. The 1972 and 1987 profiles indicate some expansion of the vegetation some places over a 15 years period (Fig. 4). The 1972 profile is narrower between distances 135 to 150 than the 1987 profile. The maximum NDVI value is at the same location (140). the profiles suggest that the vegetation, peaking at 140, has become more vigorous around the peak. This can be seen as a wider profile in the 1987 image. Seasonal factors may not be the reason for the widening of the profile because the peak NDVI values are similar in the 1972 and 1987 images. Since the cause of the shifts cannot be revealed by satellite data, a ground check is necessary to confirm vegetation changes and their cause. Numerous shifts as in figure 4 would be observed, if the predicted vegetation migration occurred.

6. Conclusion

Though large vegetational migrations have been predicted to accompany likely global warming, temperature trends show insignificant changes in Fennoscandia. This test case of vegetation boundary monitoring in northern Finland using Landsat MSS showed no clear evidence of vegetation change. Increases of NDVI which were probably caused by vegetation phenology were observed mainly in mountain birch forests. It may be difficult to detect the initial stages of vegetation change using satellite data only, but the results should provide helpful information for ground checking. Vegetation monitoring is very important for understanding the ecological environment, and the status of global vegetation. If recent predictions become true, satellite remote sensing will be the most useful tool for monitoring vegetation changes in the boreal areas. The monitoring techniques, developed in this study can be used for the long term monitoring of changes in the vegetation cover.

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Figure 1 Schematic discription of expected vegetational changes. An intensity increase as in fig. 3 will occur on AB. A boundary shift as in fig.4 will happen on CD.

Figure 2 NDVI difference image (Kevo, part). Darker gray shows decreasing NDVI greater and brighter shows increasing NDVI greater. Black shows clouds. (original; color coded)

Figure 3 Profiles observed in a mountain birch forest. The increased NDVI value might suggest a biomass increase.

Figure 4 Profiles observed in a mire. Boundary shifts are found. Unchanged peak values will suggest little phenological change in vegetation.