Use of AVHRR NDVI data to map vegetation zones in north-western Europe

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This study use the GIMMS NDVI dataset from 1981 to 1999 covering north-western Europe, and surface pollen, phenology and climatic data for the same period. By using an individual threshold NDVI value for defining the onset of the growing season applied to each pixel for each year a high correlation was found with pollen, phenology and climatic surface data. Determining the end of growing season based on a threshold NDVI value shows la lower correlation with surface the data. By using GIMMS NDVI values mean dates for onset, peak and end of growing season were related to the positions of the units of a traditional vegetation zone map. The correlation is positive regarding boreal areas, but weaker for the boreonemoral and nemoral zones. An alternative zone map based on NDVI values is presented, and the discrepancy may be explained either by diverging traditions in defining vegetation zones or by the definition of threshold values, which may not treat oceanic and continental areas equally.

I. INTRODUCTION

Vegetation zones are defined by botanic criteria (vegetation types, vegetation physiognomy and floristics) which show a positive correlation with climate. Vegetation zones can therefore also be called bioclimatic zones. They are considered to mostly reflect temperature sums, and therefore generally show a latitudinal pattern coinciding with global radiation in general, as opposed to vegetation sections which mostly manifest oceanity gradients. These vegetation zone maps can be used in a variety of ways related to global change issues, and for managing biodiversity, as they represent a good integration of climatic parameters with good spatial resolution. Recently a new vegetation zone map covering Fennoscandia, Denmark, and northwestern parts of Russia was presented by Moen (1999), and shown as Fig. 1. This map is in good agreement with other Fennoscandian maps, but Russian maps tend to have the southern zones dislocated further southwards. In northern areas the summer warmth is assumed to be the prevailing climatic factor in the north-south distribution of most plants and vegetation types. In this study phenology, pollen, climatic data, and the vegetation zone map by Moen (1999) are compared with the 1981-1999 GIMMS NDVI data-set. The objective is to evaluate whether boundaries in a traditional vegetation map can be supported by objective remote sensing data involving data from 18 years.

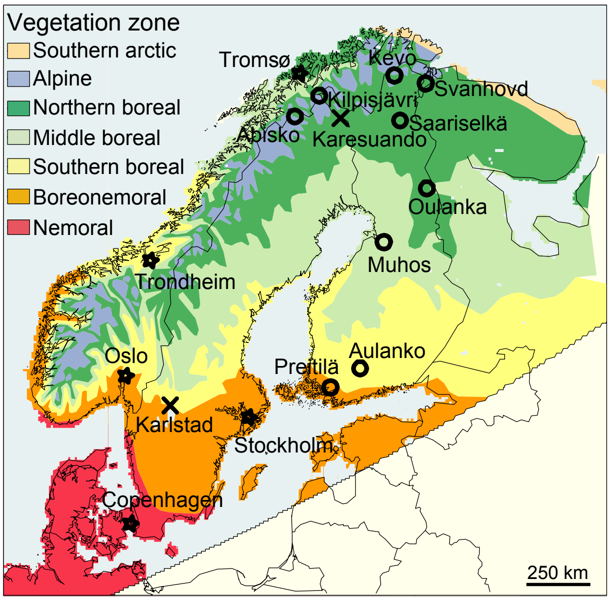

Fig. 1. Study area. Vegetation zones following Moen (1999), and the positions of the phenological observation points (circle), the pollen stations (star), and climatic stations (cross) usedin this study.

II. MATERIAL AND METHODS

A. *Phenology and pollen data*

In this study phenological data on birch (*Betula pubescens*) collected at nine measuring stations geographically distributed from southern Finland to northern Norway are used (Fig. 1). Due to the lack of phenological stations in southern parts of Scandinavia, the data-set is supplemented by pollen data from birch in this area. Birch has a strong correlation between leaf unfolding and appearance of first pollen. However, the Scandinavian countries have different methods for defining the onset of the pollen season. In Sweden (Stockholm) the first of five continuous days with pollen are used as the onset criteria. In Denmark (Copenhagen) the start of the pollen season is defined when the accumulated level reaches 2.5% of the seasonal level. In Norway (Tromsø, Trondheim, and Oslo) the criteria is equal to Denmark, but the accumulation level is defined at 5%. In this study we use the first day of +recorded pollen as a start of the onset period. However, this date could be influenced by long-distance pollen transport (Hjelmroos 1991).

B. *Meteorological data*

The meteorological data, air temperature and snow cover, recorded from Karesuando and Karlstad (Fig. 1) are used as reference data in this study. The climatic station Karesuando is situated in the northern boreal zone. Annual temperature at this station is -2.3°C, while mean July temperature is 12.8°C (Alexandersson et al. 1991). The climatic station Karlstad is situated in a transition area between the southern boreal and the boreonemoral zone. Annual air temperature at this station is 5.4°C with a mean July temperature of 16.1°C.

C. *Vegetation zone map*

The map presented by Moen (1999) is a referance used here, but some comments are necessary. In this map the alpine belt is divided in one single unit, and the concept zone is also used for division of the altitudinal gradient. Some small areas mostly in the northern parts of Norway and on Kola Peninsula (Russia) are north of the polar tree line and are classified within the southern arctic zone. In areas where the low alpine zone borders the southern arctic zone the zonal division is difficult. Due to only minor floristic differences between the low alpine belt and the southern arctic tundra in the study area, both units are treated as alpine in this study. In particular, in Norway the vegetation zone map gives a simplified representation relative to the great variation found locally in many parts of the country, and therefore does not express the coverage of the areas exactly.

D. *Satellite data*

We have used the Global Inventory Monitoring and Modelling System (GIMMS) global data-set at 8 km resolution from July 1981 to December 1999. The data-set was produced at NASA Goddard by Dr. Tucker, with data from the AVHRR onboard the afternoon-viewing NOAA satellite series. The GIMMS data set is composed of the maximum value NDVI for 15-day periods. The highest NDVI value for each composite is chosen as the NDVI for the compositing period and it corresponds to lower aerosol and cloud contamination. The GIMMS data processing include improved navigation, calibration of the four different sensors, corrections for sensor degradation and partial atmospheric correction of the data, corrections for Rayleigh absorption and scattering, and atmospheric correction for El Chichon and Pinatubo aerosols. The data-set has been used to detect biotic response to temperature change at northern latitudes (Zhou et al. 2001).

E. *Analysis*

The GIMMS dataset was georeferenced and analyzed together with phenological, pollen and meteorological data. For each pixel an 18-year mean NDVI value (NDVI > 0) for the period from 1982 to 1999 was computed. The 15 days composite NDVI value upward passing of this mean value is used as a threshold for determining the onset of the growing season at each pixel for each year. Also computed was the 18-year mean peak value. The downward passing of 1/3 of this mean peak value was used to determine the end of the growing season. These thresholds show the best correlation with onset of leafing in the spring and shedding of leaves in the autumn. These procedures also ensure sensitivity for changes in timing during the 18-year period, independent of the actual ground cover present at each pixel. Finally, when the onset and end of growing season are defined, the correlation between temperature and NDVI during the growing seasons is analyzed, and seasonal NDVI based metrics are calculated for each vegetation zone. We also present a new time integrated NDVI (TI NDVI) based vegetation zone map.

III. RESULTS AND DISCUSSIONS

A. *Onset and end of growing season*

Table I

Correlation coefficients between onset/end of growing season measured from NDVI and as defined from pollen, phenology or climatic data. DIFF. is the mean difference in number of days from the satellite based measuring of onset/end of growing season. The 0°C and 5°C are crossing upward (spring) and downward (autumn), and is based on 21 days moving average. Positions of the stations are shown in Fig. 1

STATION	TYPE OF DATA	PERIOD	R	DIFF.	RMS
SPRING					
Tromsø	Pollen	1984-99	0.72	21	23
Trondheim	Pollen	1982-99	0.59	22	24
Oslo	Pollen	1984-99	0.85	18	18
Stockholm	Pollen	1982-99	0.61	17	20
Copenhagen	Pollen	1982-99	0.64	19	21
Svanhovd	Onset of leafing	1994-99	0.63	1.3	6.1
Abisko	Onset of leafing	1982-99	0.58	-1.3	6.0
Kevo	Onset of leafing	1982-99	0.86	-0.2	4.3
Kilpisjärvi	Onset of leafing	1989-99	0.60	-0.8	10.3
Karesuando	Last day with snow	1982-98	0.66		
Karesuando	0°C	1982-98	0.51		
Karesuando	5°C	1982-98	0.74		
Karlstad	Last day with snow	1982-98	0.44		
Karlstad	5°C	1982-98	0.54		
AUTUMN					
Svanhovd	Shedding of leaves	1994-99	0.50	10.9	14.9
Kilpisjärvi	Shedding of leaves	1982-99	-0.15	-3.1	9.5
Karesuando	5°C	1982-98	0.60		
Karesuando	0°C	1982-98	-0.03		
Karlstad	5°C	1982-98	-0.14		

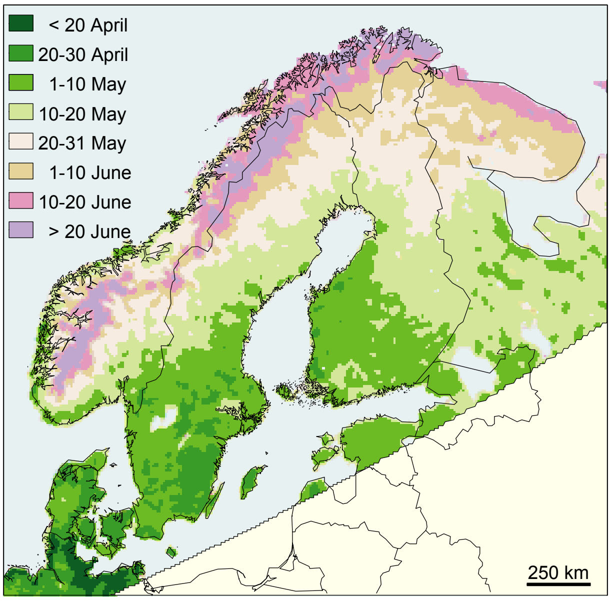

Fig. 2. Time of onset of spring. Mean values for the period from 1982 to 1999.

Tab. I shows the relationship between NDVI values in the GIMMS data set and collected phenology data (pollen, onset/shedding of leaf, temperature threshold, last day of snow). There is a tendency to higher correlation between measured NDVI values and in-situ data in northern parts in the study area. Data from the spring shows a higher correlation, compared to data from the autumn period. In spite of discrepancies in definitions of onset of pollen season, the correlations here are between 0.59 and 0.85. The differences shows that the start of the pollen season is earlier compared to NDVI based definition. This definition is based on the onset of leafing of birch. In Fig. 2 the time of onset of spring is illustrated. Only two measuring stations have long time series data for the shedding of leaves (Svanhovd, Kilpisjärvi). For both stations the correlations are low.

B. Temperature and NDVI during the growing season

For the climatic station Karesuando (Fig. 1) the correlation between NDVI and air temperature from May to September is computed to 0.75. Data sets from the period 1982-1998 are used in these computations. For the climatic station Karlstad a correlation of 0.82 is obtained for the same period by using air temperature for the period April to October. These high correlations indicate that temperature variability during the growing season is one of the most important climatic parameters influencing the variation of NDVI values. However, one should be aware that correlation is not an evidence of a direct relationship between temperatures and NDVI. The NDVI/temperature relationship is probably not linear, and will change due to geographical position, ground cover, and time of the growing season.

C. Traditional vegetation zone map and seasonal NDVI metrics

In Fig. 3 and Tab. II we have used the NDVI values in the GIMMS data to analyze the seasonal characteristics for each of the entities in the traditional vegetation zone map (Moen 1999). The late onset of spring for the alpine-/southern arctic zones is explained by this entity including also middle and high alpine areas, and the dates in the table are mean values.

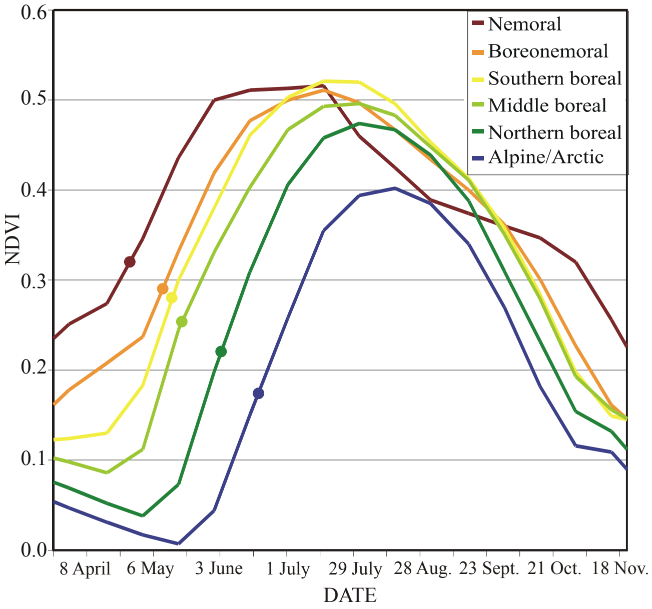

Fig. 3. NDVI profile during the growing season of the traditional vegetation zones (Moen 1999). Dots indicate the NDVI based onset value/date for the growing season, based on mean values for the period 1982 –1999.

Table II

Seasonal NDVI based metrics according to vegetation zones by Moen (1999). Mean values for the period 1982 -1999.

VEGETATION ZONE	ONSET	PEAK	END	DURATION
Alpine- / southern arctic	21 June	8 Aug.	9 Sept.	80 days
Northern boreal	3 June	29 July	15 Sept.	104 days
Middle boreal	19 May	23 July	25 Sept.	129 days
Southern boreal	12 May	17 July	23 Sept.	134 days
Boreonemoral	9 May	11 July	27 Sept.	141 days
Nemoral	2 May	4 July	11 Oct.	162 days

D. A new TI NDVI based vegetation zone map

In Fig. 4 a new time integrated NDVI (TI NDVI) based vegetation zone map is presented. TI NDVI values are calculated for each pixel during the growing seasons, and the TI NDVI values are grouped and colored for a best fit with the traditional vegetation zone map (Moen 1999, Fig. 1). To compare the geographical distribution of the vegetation zones of our new TI NDVI based map with the traditional map we have drawn the borderlines of the traditional vegetation zones on our new map on Fig. 4.

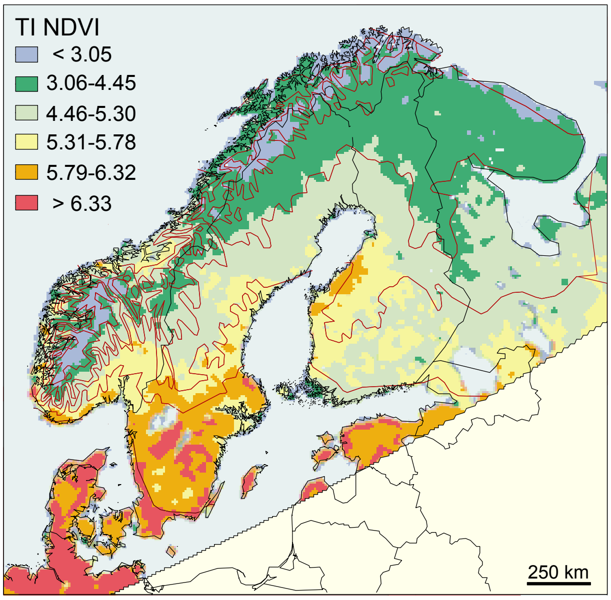

Fig. 4. A new TI NDVI based vegetation zone map, with the borderlines (red) of the zones from the traditional map by Moen (1999).

The coarse resolution of 8 km leads to a mixed-pixel problem. We observe a "colder" zone along the coast and around lakes where water and a mosaic of lowland and mountains reduce the NDVI values. Integration of a land cover mask in the classification will reduce these misclassifications.

In general there is a high agreement between the TI NDVI based map and the traditional map concerning the boundary between the alpine zone and the northern boreal zone, and between the northern and the middle boreal zone. There is also a quite good agreement regarding the middle and southern boreal zone, except for parts of Finland. Our classification of the boreonemoral and nemoral zones shows several disagreements compared to the traditional map. One explanation to these disagreements is found in the definition of the nemoral zone. Compared to boreal vegetation, species dominating the nemoral zone requires both high summer temperatures and fairly high winter temperatures. Our method does not catch the winter parameter and the map is based on an assumed correlation between vegetation zones and summer warmth, and a correlation between temperatures and NDVI during the growing season. In these more southern zones also precipitation is assumed to have higher influence on NDVI (Yang et al. 1998). Other possible explanation is that these zones are agricultural regions, and for instance the early NDVI peak of winter wheat (Rundquist et al. 2000) could influence the results. It is also known that there is a discrepancy between the definition of boreal zones or subzones between Fennoscandian and Soviet/Russian authors, and such different traditions may be inhereted in the Moen (1999) map, without sufficient explanation or knowledge about criteria to be used in a balanced way between oceanic and continental sections

IV. CONCLUSIONS

This study has demonstrated a NDVI based method of measuring onset of spring. The method shows high correlation between phenology, pollen and climatic data. Determining the end of growing season on the basis of NDVI value shows less accuracy with surface data. In the study area there is a high correlation between NDVI values and temperatures during the growing season. We have analyzed the seasonal NDVI metrics for a traditional vegetation zone map. The results indicate the possibility to use the assumed relationship between temperatures and NDVI during the growing season to develop a new TI NDVI based vegetation zone map for the boreal areas. Mapping boreonemoral and nemoral zones using the same method seems to be more difficult.

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