GIMMS-NDVI based mapping of the growing season and bioclimatic zones in Fennoscandia and neighbouring parts of NW Russia

S.R. Karlsen [a], A. Elvebakk [b], K.A.Høgda [a], B. Johansen [a], P.S.A. Beck [b]

[a] NORUT Information Technology, P.O.Box 6434, N-9291 Tromsø, Norway – (stein-rune.karlsen, kjella, bernt)@itek.norut.no
[b] Institute of Biology, University of Tromsø, Breivika, N-9037 Tromsø, Norway – (Arve.Elvebakk, pieter.beck)@ib.uit.no

Abstract – The data used in the present study is a 21-year GIMMS-NDVI dataset, surface data on phenology of birch, and temperature data from meteorological stations, all for the period 1982 to 2002. For each pixel a 21-year mean and a mean of peak NDVI value was computed. Threshold values related to this mean, and mean of peak NDVI values, which show the best correlations with the phenological field data were chosen to characterize the growing season. Then time integrated values (TI NDVI) during the growing season were computed to produce a bioclimatological map of Fennoscandia and neighbouring parts of northwestern Russia, which was tested and correlated with growing degree days (GDD) obtained from the meteorological stations. The correlation between GDD and TI NDVI data during the phenologically defined growing season was very high. Therefore, the TI NDVI map could be presented as a bioclimatic map reflecting GDD, except for the areas distorting NDVI values by their strong ground cover heterogeneity.

Keywords: Fennoscandia, GIMMS-NDVI, phenology, growing season, growing degree days, vegetation zones, bioclimatic map.

1. INTRODUCTION

Major classes of temperature sums lead to major classes of plant cover responses, which can be expressed as vegetation zones. Vegetation zones have been defined by those botanic criteria (vegetation types, vegetation physiognomy and floristics), which have been considered to show the strongest positive relationship with climate. Vegetation zones can therefore also be called bioclimatic zones. They are considered to mostly reflect temperature sums, and are therefore correlated with the latitudinal global radiation pattern. These vegetation zone maps can be used in a variety of ways related to global change issues, and for managing and describing biodiversity. The northern, middle and southern boreal zone in Fennoscandia as defined by Moen (1999) have differences in mean July temperature of 2-3 ºC, equivalent to expected changes in climate changes scenarios (e.g. Benestad 2002). Defining such bioclimatic zones is therefore a crucial element in predicting future consequences of global warming, particularly in the long run when different resilience patterns in vegetation components have been acting.

All previous attempts of mapping bioclimatic units in Fennoscandia have basically been subjective. Authors have selected those botanic criteria thought to be the best ones reflecting climate diversity. Boundaries between classes have been cartographically fixed as a combination of spatial knowledge and extrapolation along topographical features. However, there are still important disagreements, particularly between the Nordic countries and neighbouring Russia. Russian authors (e.g. Isachenko et al., 1974; Safronova et al., 1999) advocate a much more broadly defined northern boreal zone in Russia than the predominating Nordic proposals (e.g. Tuhkanen 1984, Dahl et al. 1986, Moen 1999). There is an obvious need for a more quantitative approach, primarily based on non-subjective data.

The major aim of this paper is to evaluate whether the relationship between growing degree days (GDD) and time integrated NDVI (TI NDVI) during a phenologically defined growing season on a 21-year time scale and on a broad spatial scale can be used in bioclimatic mapping of Fennoscandia and neighbouring parts of northwestern Russia.

2. MATERIALS AND METHODS

Phenology data on birch from 15 research stations (Fig. 1), and the half-month GIMMS-NDVI dataset with 8 x 8 km^2 resolution from the period 1982 to 2002 were used to characterize the growing season.

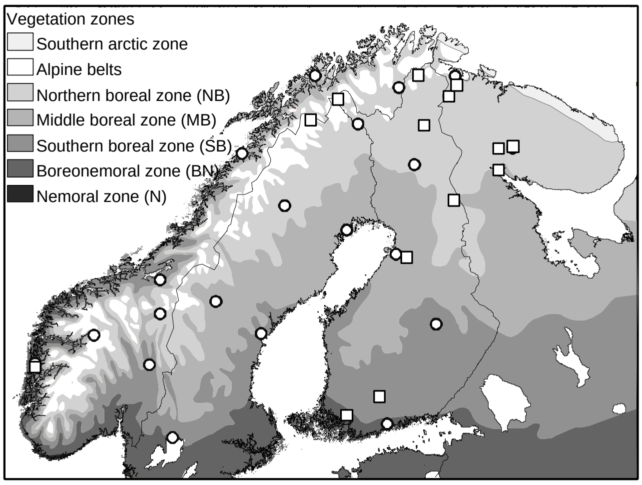

Figure 1. Vegetation zones in the study area according to Moen (1999), redrawn with permission, and showing the positions of the phenological (square) and meteorological (circle) stations used in this study.

For each pixel a 21-year mean NDVI value (NDVI > 0) and a mean of peak NDVI values were computed. The onset of the growing season was defined as the time each year when this mean NDVI > 0 value was surpassed, and the end of the growing season when the NDVI value decreased below 0.7 of mean of peak NDVI value. These thresholds showed the best correlations with the phenological field data. Then, time integrated values (TI NDVI) during the phenologically defined growing season were computed to produce a bioclimatological map of Fennoscandia, which was tested and correlated with growing degree days (GDD) obtained from 20 meteorological stations (Fig. 1). The map was also compared with. traditional bioclimatic maps, and analyzed for error factors distorting NDVI values.

3. RESULTS

3.1 Timing of the growing season

In general, the NDVI-defined onset of growing season shows higher correlation and less bias with birch phenology data during spring, as compared with data from the autumn periods. During spring, most of the stations show a moderately strong positive correlation (r = 0.5-0.8) with the NDVI data. The mean correlation value for stations with at least 20-year long time-series of onset of leafing of birch is 0.62, and all of these stations are significant on the > 5% level. Except for one station, the bias is less than one week, and the onset of the growing season in the NDVI based measurements is tuned to occur on average less than two days before onset of leafing.

The NDVI-defined end of the growing season was correlated with the phenophases '> 50% yellowing of leaves' and '> 50% shedding of leaves'. There is a tendency of higher correlation values for the northern stations, and for these stations the NDVI based defined onset of autumn fits well with the time for > 50% shedding of leaves. On the other hand, the three southern stations have mostly low correlation values, and the NDVI based measurements indicate onset of autumn before the phase '> 50% yellowing of the leaves' is reached.

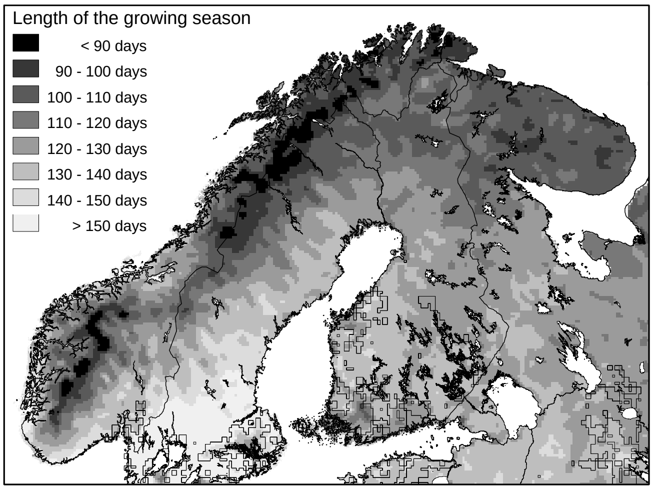

Figure 2. Length of the growing season, based on mean values from the GIMMS-NDVI dataset for the period 1982-2002. Pixels with > 20% cover of agricultural lands are shown within grids.

3.2 The relationship between GDD and TI NDVI

Very high correlation values between mean temperatures and maximum NDVI values for half-month periods during the growing season are found within a broad range of the climatic diversity in the study area. For the 21-year period, the correlation values r are between 0.77 (Kirovsk) and 0.99 (Oulu) with a mean value of 0.91. For individual years the correlation values were much lower, which illustrates that mean values of many years are necessary to obtain high correlations between temperatures and NDVI.

To study the general relationship between GDD and TI NDVI within the study area, the mean values for each meteorological station are plotted in a correlation analysis (Fig. 2). The linear regression line shows that a TI NDVI range of 0.5 corresponds to 124.5 ºC-days with a 0 ºC threshold (96 ºC-days with a 5 ºC threshold). In general, the GDD values are higher than the TI NDVI values at the oceanic stations, thus indicating a slightly steeper regression line for these stations.

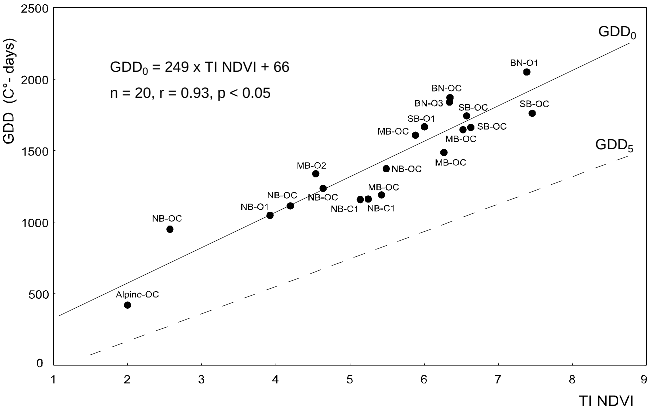

Figure 3. Relationship between GDD, with 0 ºC (GDD$_0$) or 5 ºC (GDD$_5$) in threshold temperature, and TI NDVI during the growing season, based on mean values for the period 1982-2002. Each meteorological station has a code for the ecogeographical region it belongs to.

3.3 A TI NDVI based bioclimatic map

Figure 4 shows a TI NDVI based bioclimatic map, based on mean values during the growing season during 21 years. The values are divided in 14 classes, each representing a range of 0.5 TI NDVI units. Compared with the zones in Moen (1999)(see Fig. 1), the three boreal zones mapped by Moen (1999) are mostly covered by eight TI NDVI classes, five classes cover mostly arctic/alpine areas, and one class cover mostly borenemoral (BN) areas.

The overall broad geographical patterns of the TI NDVI based map show many similarities with the traditional map by Moen (1999), but also some disagreements. The boundaries between the northern boreal (NB) zone and arctic/alpine areas are quite similar in the Moen (1999) and the present TI NDVI maps, and occur in the TI NDVI range 4.0-4.3, and in the GDD ranges 1060-1140. The two maps also show many similarities concerning the boundary between the NB zone and the middle boreal (MB) zone, which occurs in the range 1380-1460 ºC-days.

With some exceptions, there is also a quite good agreement regarding the boundary between the MB and the southern boreal (SB) zone. Southeastern Finland is characterized by a high density of lakes, which leads to a decrease of the NDVI values. Here, areas belonging to the SB zone have TI NDVI values in the range 6.5-7.5. Contrastingly, the SB zone in other regions displays TI NDVI values are in the 7.0 - >8.0 range. If these problem regions are avoided, the boundary seems to occur mostly in the range 1760-1880 ºC-days.

The boundary between the SB and BN zones is highly influenced by agriculture, which is dominant in the southern part of the study area where this boundary occurs. It is therefore difficult to interpret a temperature threshold for this boundary on the TI NDVI based map, but it is most likely at about 2100 ºC-days. The BN zone is mapped only with a small number of pixels on the TI NDVI map, within an area which to a high degree is also masked by the agricultural land-use symbol, not mapped by the TI NDVI based method.

The map by Moen (1999) has a generally higher geographical resolution in areas dominated by fiords and mountains, this is in particular shown in most of western Norway, and in Nordland County and the Lofoten area in northern Norway.

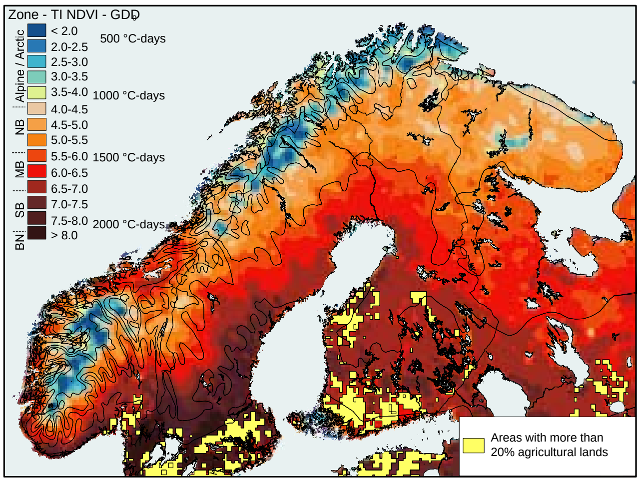

Figure 4. A bioclimatic map of the study area. The TI NDVI values are related to GDD for the period 1982-2002. The 14 different climate classes each represent a range of 0.5 TI NDVI units or a range of 124.5 °C-days, and are shown with different colours. The boundaries between zones as mapped by Moen (1999) are also shown.

4. DISCUSSION AND CONCLUSIONS

4.1 Characterizing the growing season

New algorithms for defining the onset and end of the growing season were developed in this study and adapted to the ecological conditions of a northern area like Fennoscandia. The strength of the present methods is that they are based on correlations with observed phenophases of the widely distributed species *Betula pubescens*. The methods presented here are reasonably independent of the actual land cover within each pixel, and focus on the ecological responses to temperatures taking place within the ground cover, as opposed to most other satellite-based phenology studies which only use theoretically defined NDVI phases. The present approach has a higher NDVI threshold value during autumn as compared to spring.

The conclusion is that the phenology map shown here (Fig. 3), based on linking NDVI data with surface phenology data, are better extrapolated cartographically to a regional area, than alternative maps based on ground truth phenology or temperature data alone. The onset and the end of the growing season are both obviously important parameters, and are applied within the next step, which is to integrate TI NDVI values during the phenologically defined growing season and correlate them with measured GDD during the same periods.

4.2 The GDD - TI NDVI relationship

At individual pixel level several other factors than local temperatures determine biomass and, consequently, affect TI NDVI values. It is well known that NDVI values vary with vegetation type, nutrient conditions, soil background, and illumination conditions. Regarding vegetation diversity, broadleaved forests have been shown to have higher peak NDVI values than coniferous forests. The difference is, however, likely to be lower for TI NDVI values, since coniferous forests have higher NDVI values at the onset and at the end of the growing season. On a vegetation type-scale, TI NDVI values vary a lot within short distances, even within equal temperature conditions. However, the 8 x 8 km^2 resolution used here integrates the mosaics on a local scale, so that the resulting large pixels are a much better reflection of the biomass response to the climate, than any smaller size where the spatial variation would be much greater.

The existence of water bodies in pixels obviously decreases TI NDVI values. Mixture with water bodies within each 8 x 8 km^2 pixel occurs, but more in some areas than in others. In southeastern Finland lakes have a very high prevalence and terrain cover, and the TI NDVI values here are low as compared with the vegetation zone the area belongs to. This shows that it is not possible to obtain a reliable GDD - TI NDVI relationship in such areas when working at a spatial resolution of 8 x 8 km^2. There are also some lower TI NDVI values along the coast, in particular along parts of the Norwegian coast with a mixture of fiords and steep, high mountains. Here shadows cause a decrease in TI NDVI values. However, the median filtering applied removed most of these sea or mountain affected mixed pixels, but not the mountain pixels affected by shadows and/or glaciers.

The temperature - NDVI analysis shows that inter-annual variations were smoothed out by prolonging the time period, resulting in much higher r values for the 21-year period than for shorter periods of time. We therefore believe that at least a decade long time-scale is necessary for making a correlation analysis of this kind. The high correlation values obtained indicate that GDD is the most important climatic parameter influencing the TI NDVI values, and that the temperature sum is the dominant control at this scale, both temporally and spatially.

The present study is the first in the study area that combines a phenology defined onset and end of the growing season with TI NDVI data, both based on decade scale data sets. Our conclusion is that this is a sound approach, which allows for a more objective bioclimatic classification, except for areas where spatial heterogeneity in altitude and water surfaces and agricultural practices distort NDVI values.

4.3 Comparison of the TI NDVI based bioclimatic map with traditional vegetation zone maps

The disagreement between most Russian and Fennoscandian authors about the definition of boreal bioclimatic zones, results in a lack of congruence in the NB/MB boundary equivalent to as much as 0.5-1.0 zonal unit (see Bohn et al., 2000). The TI NDVI based map supports the extrapolation of the Fennoscandian defined boundary into Russia, as done by Moen (1999). Extrapolation of the NB/MB boundary from Russian maps into

Fennoscandia is difficult due to all the lakes in southeastern Finland. The selection of major zonal units is a process that both attempts to subdivide an area in more or less climatically equal ranges, and to have these units well-defined by botanic criteria. In respect to the former, the present study supports the zonal boundaries proposed by Moen (1999), because the three units are defined within the approximate GDD ranges 1090-1400, 1400-1800, and 1800-2100, respectively. The Russian tradition has the NB/MB boundary in the range 1600-1700, which climatically results in NB occupying about half the temperature range within the boreal area, and this boundary therefore would be better applied to a system dividing the boreal are**a** in two and not three subunits. Future attempts should try to harmonize also criteria which have been use to delimit the zones in Fennoscandia and Russia, knowing that many of these criteria are more strongly depending on the sectional gradient than the zonal gradient.

The treatment of the northern Kola Peninsula as boreal by the CAVM Team (2003) is not supported here. The TI NDVI based map shows that the northernmost coast of Kola Peninsula has TI NDVI values equivalent to those mapped as arctic/alpine in Fennoscandia, and supports its position as arctic.

5. ACKNOWLEDGEMENTS

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