Mapping and Modelling the Snowmelt and Greening Pattern in Southern Norway by Combining Microwave and Optical Remote Sensing Sensors

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***Abstract* - Southern Norway has strong climatic gradients and is well suited for studying snow melt and greening patterns. In this study we combine snow cover maps with phenological maps for the early May period for the years 2004 and 2006. The snow cover area maps are based on both microwave (ASAR) and optical (MODIS) sensors. The phenological maps are based on NDVI thresholds from the MODIS sensor. The onset of growing season 2004 was among the earliest recorded over the last 30 years. On May 8, 2004 30% of the study area was covered by snow and 29% had unfolded leaves on trees. The onset of the growing season in 2006 was slightly later than average, and on May 4, 2006 64% of southern Norway was covered by snow and the phenophase of unfolded leaves had not started yet.**

Keywords-component; Southern Norway, snow cover maps, phenological maps

I. INTRODUCTION

Phenology, in its simplest terms, is a study of cyclic events of nature. An immediate and observable effect of global warming is a shift in the seasonal phenological cycle, which is often the first indication of transition in ecosystems. In winter, snow cover protects plants and soil from the low air temperatures above. In spring, however, snow cover prevents warming of the soil. Once the snow has melted, solar radiation falls directly on the soil surface, the soil begins to thaw and plant life is activated. In spring, in southern Norway (April-June), the solar radiation is high, and changes in the timing of snowmelt would lead to large differences in the amount of heat plants receive. Since the northern distributions of many boreal and alpine plants have adapted to the temperature sum for the growing season, even small changes in the snowmelt-greening cycle on an decadal time-scale would lead to large changes in the northern distribution of plants. Changes in the snow melt and greening patterns would also change the climatic feedback. Hence, it is of significant importance to monitor the year-to-year changes in the snowmelt and greening patterns.

In this study we use snow cover maps based on the combination of microwave (ASAR) and optical (MODIS) sensors. The snow cover maps are then combined with phenological maps based on pixel-specific NDVI thresholds from the MODIS sensor. The phenological maps show the degree of greening. The aim of the study is to map the snowmelt and greening patterns in early May for the years 2004 and 2006.

A. Study area

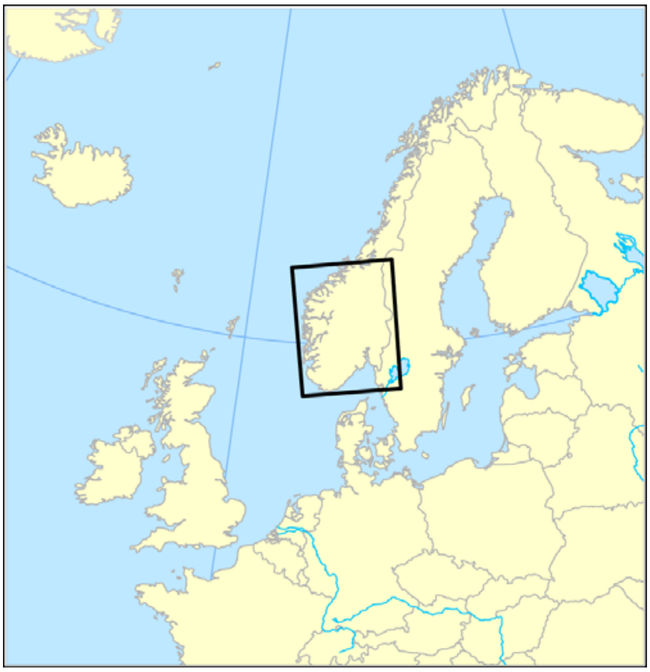

Figure 1. The study area, southern Norway.

Karlsen, S.R., E. Malnes, J. Haarpaintner & R. Solberg. 2007. Mapping and Modelling the Snowmelt and Greening Pattern in Southern Norway by Combining Microwave and Optical Remote Sensing Sensors. Proceedings for IGARSS. 23-27 July 2007, Barcelona.

The study area of southern Norway and neighbouring parts of Sweden, is a region of about 225,000 km^2 (Fig. 1). The snow melt and greening of vegetation mainly follow the altitude gradient, and about 20% of the area is above 1000 meters in altitude. The climatic range in terms of mean July temperature is from about 14-17 °C in the lowland to typically less than 7°C above 1000 meters altitude. In addition, the oceanic-continental gradient is strong: the western coast is highly oceanic with a yearly monthly mean temperature range of less than 12°C and about 80 days with more than 10mm precipitation; in the continental interior the figures are 22°C and less than 10 days, respectively [1,2,3].

II. MATERIALS AND METHODS

A. *Snow cover area mapping*

In this study we use snow cover maps based on multitemporal/multisensor combinations of microwave (ASAR) and optical (MODIS) sensors. The maps have 250m spatial resolutions and daily coverage, and are based on single and multisensor algorithms developed in the Framework Programme 5 project EnviSnow. The MODIS based snow maps use the NLR-algorithm [4] to classify MODIS Level 1B products into a fractional snow cover area map (0-100%) based on a linear scaling of the radiance between snow free and snow covered calibration areas. The ASAR algorithm uses the Nagler & Rott method [5] to detect wet snow by comparing the current SAR image to a dry snow reference image. Dry snow is postulated above the local wet snow line by using a high-resolution digital elevation model [6]. Both SAR and optical snow cover maps are accompanied by confidence maps that assign a confidence (0,100%) to each classified pixel. The confidence is model based and assigns low numbers to pixels that are less likely to be correctly classified (dry snow, high incidence angles, vicinity to clouds) and high numbers to pixels that more likely to be classified correctly (wet snow, cloud-free, low incidence angle).

The multitemporal/sensor algorithm [7] gives the most probable snow coverage for the current day based on the available single sensor snow maps from the same day, and multisensor snow map from the previous day. The confidence of classified pixels from previous days is, however, reduced. Information from up to 7 days is allowed. In this way, a close to cloud-free time series of snow maps can be generated.

B. *Phenological mapping*

The MODIS 16-day composite NDVI dataset with 250 m spatial resolution (the MOD13Q1 product) was used in the study. To calibrate the composites and to map the phenophases we used recent methods developed for northern Fennoscandia [8]. The calibration is based on replacing cloud-affected 16-day NDVI composites by the mean value of the composites for the periods immediately before and after. The mapping of the onset of growing season is based on a combined pixel-specific NDVI threshold and decision rule-based method. To evaluate the results we used phenological data on birch collected by about 35 schools belonging to the school network 'miljolare.no'. The phenophase onset of growing season was defined as the point at which onset of leafing of birch occurred. About 90% of the school-observations on birch of onset of leafing fit with the MODIS-based date for onset of growing season.

C. *Combining snow cover and phenological maps*

Both the snow cover maps and the MODIS 16-day composite NDVI dataset used in the phenological mapping can be seen at: http://sivert.itek.norut.no/SnowVegetation-en.php. In ArcGIS 9.2 we combined the different products. First we found dates/periods less affected by atmospheric condition and with general good data quality. The aim was to merge together complete composites of the snow cover and greening patterns with a twice-monthly time resolution (the 1st and 15th each month). Since parts of the areas on the actual twice-monthly date are likely to have poor data quality, in these cases we used the closest dates before and after with acceptable quality to replace these areas. We used linear interpolation to account for the time difference in degree of snow cover and the time difference between different phenophases. When we merged the different products, the snow cover maps were given higher priority than the phenological maps, with a consequence that no MODIS-NDVI based phenophases should occur before 100% snow free conditions were observed in the snow cover area maps.

In this presentation, we show the snowmelt and greening patterns for the dates 8 May 2004 and 4 May 2006 since these are good examples of dates with only scattered cloud cover. These dates also illustrate well the differences from year-to-year in snow cover and greening patterns. However, clouds still affected some areas on these dates. These specific parts were mapped using cloud-free areas found in dates before or after. The snow cover maps were initially classified with 0-100% snow cover, and four phenophases were distinguished. The products presented here are reclassified to include two snow and two phenophase classes.

III. RESULTS

Figure 2 show large differences in the snowmelt and greening pattern for the early May period between the years 2004 and 2006. On 8 of May 2004 30% of the pixels had snow cover and 64% of the pixels 4 May 2006 (Table 1). In other words, in early May 2006 there were 75,000 km^2 more areas covered by snow compared with the approximate same date two years earlier. On 8 of May 2004 29% of the area correlates with the unfolding of leaves on birch, while this phenophase had not occurred yet on 4 of May 2006. In other words, in early May 2004 we found about 62,000 km^2 with green leaves on birch trees in southern Norway, while in early May 2006 green leaves was not found at all. Both years, the snow melting and greening pattern clearly follow the altitude gradient, and to some degree the oceanic-continental gradient with early greening at the oceanic western coast (Fig. 2).

TABLE I. PERCENT COVER OF DIFFERENT PHENOPHASES.

	8 May 2004	4 May 2006
Unfolded leaves	29	0
Onset of growing season	14	7
Snow free / beginning of greening	27	29
Snow	30	64

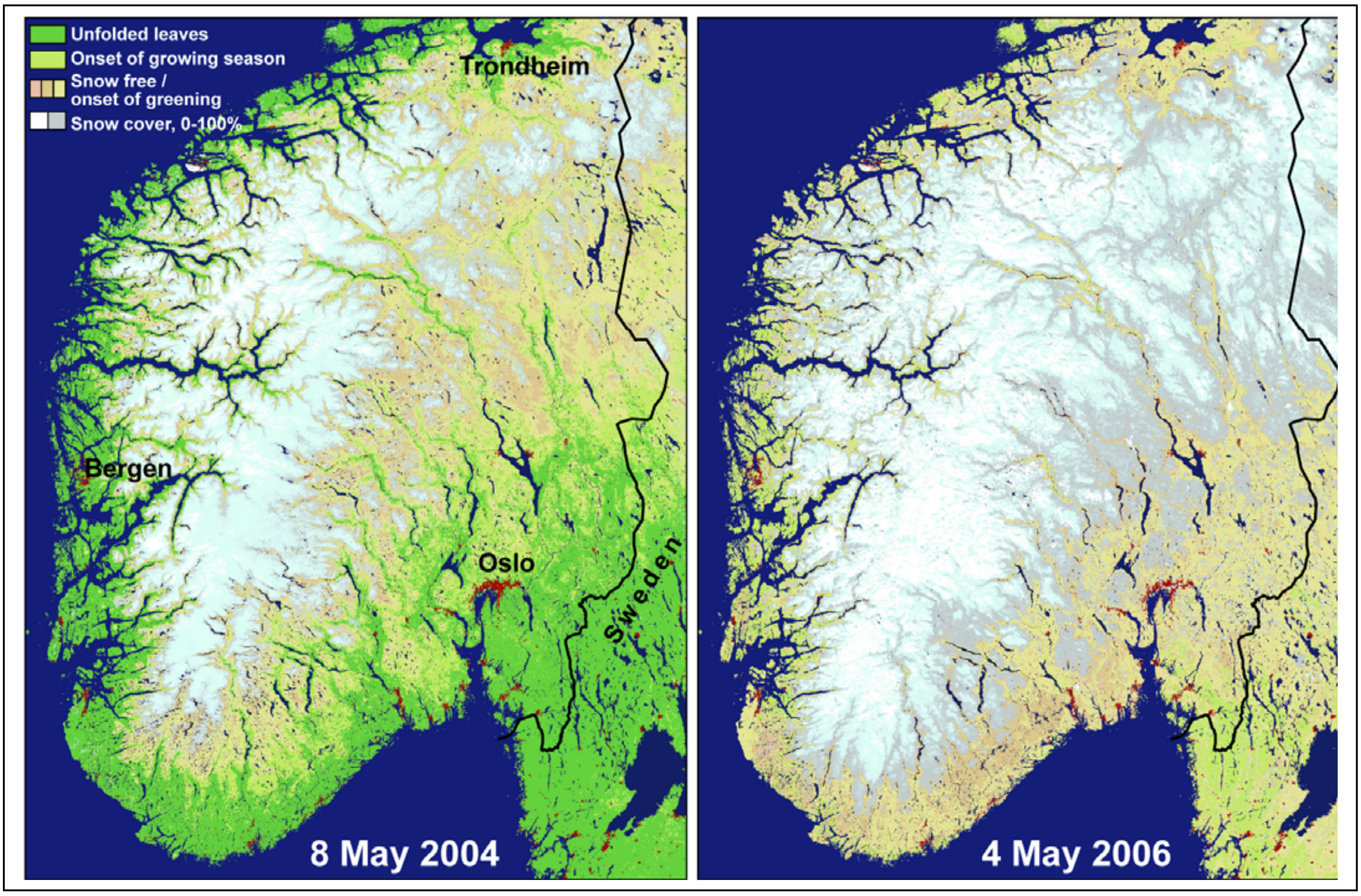

Figure 2. Snowmelt and greening pattern in southern Norway, 8 May 2004 and 4 May 2006. Urban areas are shown in red.

IV. DISCUSSION

This study has revealed large differences in snowmelt and greening patterns in early May between the years 2004 and 2006. The onset of growing season 2004 was one of the earliest recorded in southern Norway the last 25 years [9,10,11]. The timing of snowmelt and greening in spring 2004 may provide an indication of the trends expected for a normal year around 2030 based on climatic change scenarios which predict a 2°C increase of spring temperature. The onset of growing season 2006, on the other hand, was slightly later than the 1982-2002 average [10,11]. Together these maps could be use as reference years for a normal and a future year. Earlier snowmelt would also result in lower albedo and an immediate increased local temperature. On a decadal time scale, early snowmelt and greening could change alpine heaths to forests, where forest has lower albedo and less latent heat flux and thereby increased local temperature [12].

ACKNOWLEDGMENTS

We are grateful to all pupils and teachers participating in phenological field data collection in the school network 'miljolare.no'. Satellite imagery was acquired under ESA Envisat AO contract # 785 and from NASA. Parts of the study were financed by the EC project EnviSnow

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