Kristin Böttcher[1], Mika Aurela[2], Kimmo Rautiainen[2], Sophia Walther[3], Ali N. Arslan[2]
1 Finnish Environment Institute (SYKE), Mechelininkatu 34a, Helsinki, Finland, Kristin.Bottcher@ymparisto.fi | 2 Finnish Meteorological Institute (FMI), Erik Palménin aukio 1, Helsinki, Finland | 3 GFZ German Research Centre for Geosciences, Potsdam, Germany

http://monimet.fmi.fi

SATELLITE-OBSERVED PHENOLOGY OF BOREAL CONIFEROUS FORESTS

INTRODUCTION

Boreal forests are an important component of the global carbon budget as they store about one third of the global forest carbon stocks. As a consequence of climate change, temperature changes in boreal forests are predicted to be higher than in all other forest types and the timing of photosynthetic activity is likely to undergo changes. The length of the vegetation active period is thought to increase, leading to changes in the carbon uptake and release by vegetation and in the strength of the vegetation feedbacks to the climate system (Richardson et al. 2013). For the monitoring of these changes and for calibration and validation of carbon balance models, remote sensing can provide valuable information over large areas. For evergreen coniferous forests, current operational phenology products, e.g. MODIS Land Cover Dynamics product (MCD12Q2), are biased as they track the greening and colouring of leaves.

OBJECTIVE

We investigate the usability of remote sensing observations as a proxy for the start and end of the vegetation active period in boreal coniferous forests in Finland. For this, we compare satellite data sets with the CO_2 flux tower observations at three coniferous forest sites. Sites are located in the northern (Kenttärova and Sodankylä) and southern (Hyytiälä) boreal phytogeographical zones. The dominant tree species in Sodankylä and Hyytiälä is Scots pine (*Pinus silvestris*) and in Kenttärova Norway spruce (*Picea abies*).

METHODS

We determined reference dates for the start and end of the vegetation active period from the continuous CO_2 flux measurements with the eddy covariance method at three coniferous forest sites in Finland. Start and end dates were defined as the day on which the CO_2 uptake exceeds, and accordingly falls below, the 5%, 10% and 15% level of the growing season maximum of the gross photosynthesis index (PI).

Diverse remote sensing observations were compared to the field observations:

- Fractional Snow Cover (FSC) calculated from MODIS observation with the algorithm by Metsämäki et al. (2012) at 0.005° x 0.005° resolution 2001-2016
- Normalized Difference Vegetation Index (NDVI) from MODIS observations at 0.0025° x 0.0025° resolution, 2001-2016
- Soil freeze and thaw state determined from Soil Moisture and Ocean Salinity (SMOS) data at 25 x 25 km² resolution by Rautiainen et al. (2016), 2010-2015
- Sun-induced chlorophyll fluorescence from measurements of the GOME-2 instrument retrieved by the GFZ German Research Centre for Geosciences, with native pixel size of 40 x 80 km², 2007-2016.

The start of season day in coniferous forest in Finland was mapped using a proxy indicator based on Fractional Snow Cover time series (Böttcher et al. 2014, Figure 1A).

RESULTS AND DISCUSSION

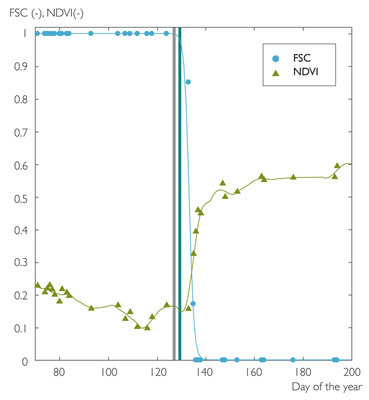
The time when Fractional Snow Cover decreases and first snow free patches are visible on the ground in spring, correlated with the start of the photosynthetically active period (PI threshold 15%) in coniferous boreal forest sites in Finland (R^2=0.89, RMSE=5 days, Böttcher et al. 2014). Similarly, the time when the ground starts to be continuously snow-covered, as observed from in situ observations of snow depth, was found to be a good proxy for the end of season (Figure 2A) and significant site-wise correlation were obtained at northern boreal sites Kenttärova and Sodankylä (PI threshold 10%, R^2>0.6). Due to high uncertainties in the retrieval of FSC from optical instruments at low sun elevations and long periods of cloud cover, the observations are not usable for the mapping of the snow accumulation period at northern latitudes.

Likewise, the quality of NDVI time-series was low at the end of autumn and NDVI threshold values were not applicable for the extraction of the end of season in coniferous sites. The soil freeze states, partially frozen and frozen up to 10 cm, were well correlated (R^2>0.70) with end of season indicators (PI thresholds 5% and 10%). Highest correspondence was obtained between the day of partially frozen soil and end of season indicator based on the PI threshold 10% (Figure 2B).

In contrast to FSC and soil freeze, sun-induced chlorophyll fluorescence is a direct proxy for photosynthetic activity. While its application for the detection of the start of season at northern boreal sites looks promising (Figure 1B, Walther et al. 2016), the end of season remains challenging. This is because of the higher noise level at large sun zenith angles that requires further investigations.

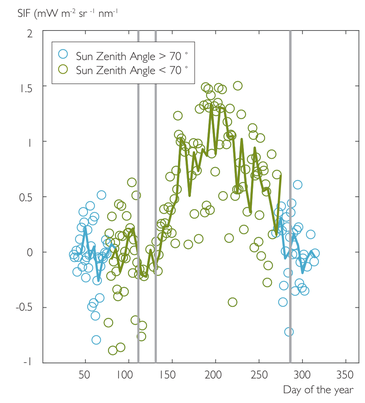
Maps of the start of the vegetation active period in coniferous forests were produced for the period 2001-2016. In south-western Finland the vegetation period starts on 22-31 March and shifts by 1-20 May in the northernmost areas (Figure 3A). In an early example year the season start occurred already by mid-March in south-western Finland (Figure 3B), and was delayed to 11-20 April in southern parts of the country (Figure 3C). Uncertainty in the estimate stems mainly from missing observations due to cloud cover and varies from year to year and by region depending on weather conditions.

FIGURE 1A



Temporal profile of the Fractional Snow Cover in comparison to the NDVI for spring 2010 at the Sodankylä site, Northern Finland. The vertical grey line indicates the start of season (07.05.2010) with the PI-threshold of 15% and the blue line shows the satellite-derived day.

FIGURE 1B



Temporal profile of the satellite-observed sun-induced fluorescence at Sodankylä in 2014. Vertical grey lines indicate the start and end of season based on PI-thresholds 10 and 15%.

FIGURE 2A

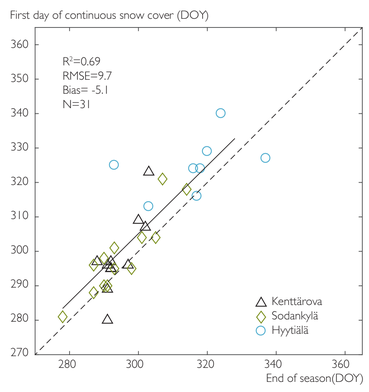
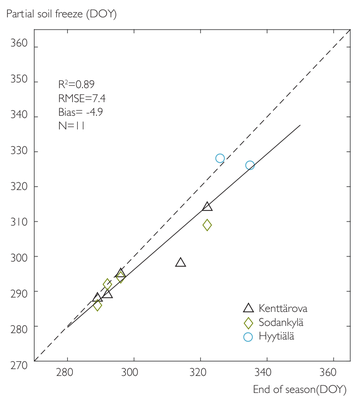


FIGURE 2B



Scatterplot of (A) the end of the vegetation active period (PI threshold 10%) versus the first day of continuous snow cover from in situ snow depth measurements and (B) the day of partially frozen soil in autumn at three CO_2 flux measurement sites in Finland. DOY is the day of year.

FIGURE 3A

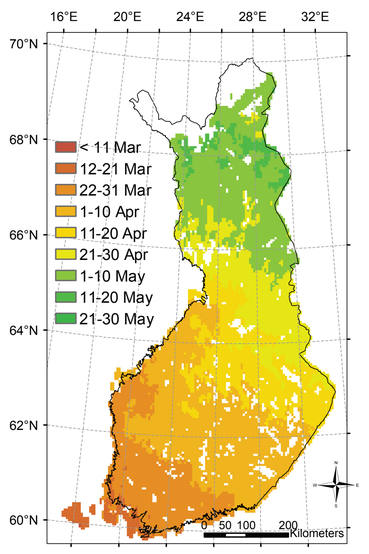


FIGURE 3B

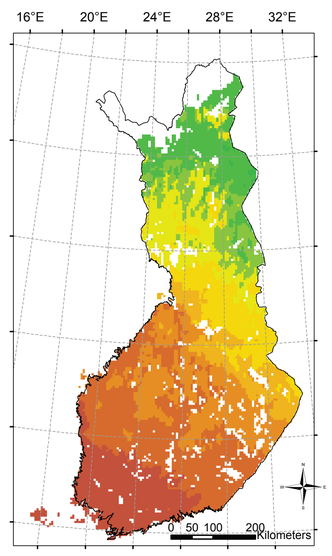
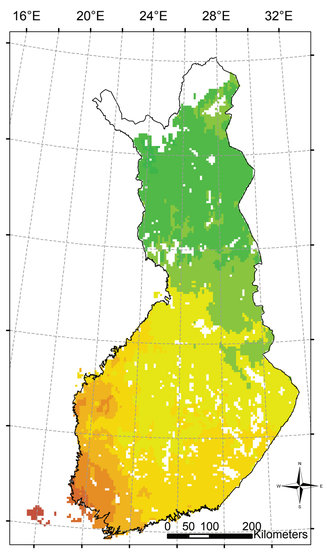


FIGURE 3C



Start of the vegetation active period in coniferous forest for (A) an average period of 2001-2016, (B) a phenologically early year (2007) and (C) a phenologically late year (2012).

CONCLUSIONS AND OUTLOOK

We studied the usability of various remote sensing indicators for the detection of the start and end of the vegetation active period in boreal coniferous forest in Finland. Snow cover decrease in spring was applied in the mapping of the start of the vegetation period with good accuracy. The publication of the maps through the open data portal of the Finnish Environment Institute is ongoing. The use of optical satellite observations for the detection of the end of the vegetation active period was hindered by low sun elevation in autumn and long period of cloud cover. Instead, soil freeze state from SMOS data appeared to be a feasible indicator for its detection. The applicability of satellite-observed sun-induced chlorophyll will be investigated further.

ACKNOWLEDGMENTS
The work was funded by the European Commission through the Life+ project MONIMET (Grant agreement LIFE12 ENV/FI000409). MODIS Level-1B data were acquired from Land and Atmosphere Archive and Distribution System at Goddard Space Flight Center of the National Aeronautics and Space Administration (http://ladsweb.nascom.nasa.gov/). We thank Mikko Kervinen from the Finnish Environment Institute for the processing of MODIS time series.

REFERENCES

Böttcher, K., Aurela, M., Kervinen, M., Markkanen, T., Mattila, O.-P., Kolari, P., Metsämäki, S., Aalto, T., Arslan, A.N., & Pulliainen, J. (2014). MODIS time-series-derived indicators for the beginning of the growing season in boreal coniferous forest — A comparison with CO_2 flux measurements and phenological observations in Finland. Remote Sensing of Environment, 140, 625-638..
Metsämäki, S., Mattila, O.-P., Pulliainen, J., Niemi, K., Luojus, K., & Böttcher, K. (2012). An optical reflectance model-based method for fractional snow cover mapping applicable to continental scale. Remote Sensing of Environment, 123, 508-521.
Rautiainen, K., Parkkinen, T., Lemmetyinen, J., Schwank, M., Wiesmann, A., Ikonen, J., Derksen, C., Davydov, S., Davydov, A., Boike, J., Langer, M., Drusch, M.T., & Pulliainen, J. (2016). SMOS prototype algorithm for detecting autumn soil freezing. Remote Sensing of Environment, SMOS special issue, 180, 346-360.
Richardson, A.D., Keenan, T.F., Migliavacca, M., Ryu, Y., Sonnentag, O., & Toomey, M. (2013). Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. Agricultural and Forest Meteorology, 169, 156-173.
Walther, S., Voigt, M., Thum, T., Gonsamo, A., Zhang, Y., Köhler, P., Jung, M., Varlagin, A., & Guanter, L. (2016). Satellite chlorophyll fluorescence measurements reveal large-scale decoupling of photosynthesis and greenness dynamics in boreal evergreen forests. Global Change Biology, 22, 2979-2996.