LIFE Project Number

ENV/FIN/000133

Final progress report on extracted features (2001-2010)

Reporting Date

31/12/2011

Action

Action 7: Methodological development and implementation

LIFE+ PROJECT NAME or Acronym

SNOWCARBO

Author

Name Beneficiary	Finnish Environment Institute (SYKE)
Contact person	Kristin Böttcher
Postal address	P.O. Box 503, FI-00101 Helsinki, Finland
Telephone	+ 358-401-876447
Fax:	+ 358-9-40300690
E-mail	Kristin.Bottcher@ymparisto.fi
Project Website	http://snowcarbo.fmi.fi

Table of contents

List of abbreviations

CLC 2000	Coordinated Information on the European Environment (CORINE) Land Cover 2000
Doy	day of year
FMI	Finnish Meteorological Institute
GPP	Gross Primary Production
JRC FAPAR	Joint Research Centre Fraction of Absorbed Photosynthetically Active Radiation
METLA	Finnish Forest Research Institute
MODIS	Moderate Resolution Imaging Spectrometer
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NEE	Net Ecosystem Exchange
NEP	Net Ecosystem Productivity
SYKE	Finnish Environment Institute

Summary

This report documents progress on the extraction of carbon-balance related features from time-series of vegetation indices in SnowCarbo action 7.
NDVI time-series from coniferous forest sites were examined for the extraction of phenological events, such as the seasonal vegetation peak and the end of growing season.
Methods for determination of these events from satellite data are described and satellite-derived phenological indicators are compared with *in situ* dates.

Introduction and objectives

The aim of action 7 is the extraction of carbon-balance-related indicative features from vegetation index time-series, which include (i) date of the beginning of growing season; ii) date of seasonal vegetation peak and (ii) date of end of seasonal vegetation growth. The methodology for the extraction of the beginning of the growing season for different vegetation types were described in an earlier deliverable of action 7 "Progress report on extracted features (2001-2008)" (31/08/2010). In this deliverable, we focus on the extraction of the time of vegetation peak and end of seasonal vegetation growth in evergreen coniferous forest, which is the dominant vegetation type in our region of interest.

In comparison to the start of season, detection of the end of growing season from satellite observations has been shown to be more challenging in several studies (for example Delbart *et al.*, 2005; Karlsen *et al.*, 2008), especially in northern latitudes due to low sun elevation in autumn, which increases atmospheric effects, and furthermore large observation gaps due to permanent cloud cover.

Methods for the satellite-retrieval of the end of growing season in northern latitudes based on optical data were developed by Delbart et al. (2005) and Karlsen et al. (2008) using as reference values field observations of onset of leaf colouring of deciduous trees. Results for the detection of growing season end showed in general low correlation with field observations, both from Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), and the end of season could not be accurately mapped. Karlsen et al. determined the end of growing season in Fennoscandia when NDVI decreased below 95% of its multi-year summer mean; only for 3 out of 12 sites correlations between field observations of birch leaf colouring and satellite-derived end of season were significant. The NDVI-based end of growing season occurred in general later (11/12 sites) than field observations. In order to improve the performance of satellite-based methods for the extraction of the end of season, Rauste et al. (2007) used in addition to highly aggregated MODIS-based autumn colour indices also phenological field observations in order to retrieve an autumn colourization state.

Autumn phenological indicators determined from CO_2 flux measurements were compared with satellite-derived indicators for temperate and boreal forests by Richardson et al. (2010). For evergreen coniferous forests no significant correlation between the satellite-derived end of season indicator (here: the falling half-maximum Joint Research Centre Fraction of Absorbed Photosynthetically Active Radiation, JRC FAPAR) and Net Ecosystem Productivity (NEP), sink-source transition were observed, whereas the correlation was significant for deciduous sites. Week correlations between radar-based end of growing season estimate (general timing of seasonally frozen temperature in fall) and field observations were found by Kimball et al. (2004), which was attributed to the importance of light availability and other environmental controls on autumn phenology. The radar-estimate was 4 to 3.5 weeks later than the observed end of the growing season.

In this report, we used NDVI time-series for the retrieval of phenological indicators related to seasonal vegetation peak and end of growing season. In the next section data sets will be shortly described. The methodology for extraction of phenological indicators from NDVI time-series will be given in chapter 3 and comparisons with *in situ* observations will be shown in chapter 4, followed by conclusions.

Data sets

MODIS time-series and processing

MODIS NDVI time-series used here were described in report "2nd EO data document (years 2001-2019)" (30/11/2010) by SnowCarbo action 3.
Filtering and interpolation of NDVI time-series were specified in three previous deliverables of action 7 "Progress report on filtered time series (2001-2008)" (31/05/2010), "Progress report on extracted features (2001-2008)" (31/08/2010) and "2nd progress report on filtered time-series (2001-2008)" (30/11/2010).

For extraction of the date of end of growing season in evergreen coniferous forest, NDVI temporal profiles were smoothed and gap-filled using a double logistic function fitted to the NDVI time-series (Jönsson and Eklundh, 2004). Missing observations in winter were filled with a site-based mean dry-snow-NDVI value using a long time statistical average of first covering snow cover (winters 1970/71-1999/00) as date for the beginning of snow cover in winter (http://en.ilmatieteenlaitos.fi/snow-statistics, last access 15/12/2011).

In situ data

CO_2-flux-based phenological indicators for the end of growing season were determined for three *in situ* sites in coniferous forest: Hyytiälä, Sodankylä and Kenttärova (see Table 1).

Table 1. Measurement sites in coniferous forests and characteristics of extracted areas from MODIS satellite data.

Site	Observation/ Organisation	Latitude/ Longitude [°]	Vegetation type	Number of NDVI pixels *	CLC 2000 class (class number)**	Threshold for land cover fraction [%]
Hyytiälä	CO_2 flux/ University of Helsinki (CARBOEUROPE)	61°51' N 24°17' E	coniferous forest (Scots pine)	175	coniferous forest (19,20,21)	100
Sodankylä	CO_2 flux /FMI	67°21.712'N 26°38.270'E	coniferous forest (Scots pine)	27	coniferous forest (19,20,21)	100
Kenttärova	CO_2 flux /FMI	67°59.234'N 24°14.583'E	coniferous forest (Norway Spruce)	19	coniferous (19,20,21)	95

* Pixel size for NDVI 0.0025 degrees.
** Class number according to Coordinated Information on the European Environment (CORINE) Land Cover 2000 (CLC 2000) for Finland (Härmä *et al.*, 2005).

The following criteria were used for determination of phenological indicators related to the end of season from CO_2 flux measurements:

(i) when daytime Net Ecosystem Exchange (NEE) in autumn first decreases below 20% of the maximum summer uptake (most negative NEE) according to Suni et al. (2003) and Thum et al. (2009) and hereafter denoted as 20% NEE; and

(ii) when Gross Primary Production (GPP) falls permanently below a certain threshold level of the growing season maximum: 50%, 40%, 30% and 15%. The growing season maximum was defined as the 98th percentile of GPP values during the month of highest uptake for a multi-year period. Phenological indicators were calculated by SnowCarbo action 4 and are hereafter denoted as 50% GPP, 40% GPP, 30% GPP and 15% GPP.

Phenological indicators determined according to criteria (i) and (ii) for years 2001-2010 are listed in Table 2 and illustrated in Figure 1.

Table 2. Phenological indicators for the end of growing season from three CO_2 flux measurement sites in coniferous forest. Criteria for determination of phenological indicators are described in the text above.

Site and year	20% NEE (doy)	50% GPP (doy)	40% GPP (doy)	30% GPP (doy)	15% GPP (doy)
Hyytiälä					
2001	309	275	295	308	*
2002	*	269	277	288	303
2003	*	280	291	312	*
2004	308	291	291	309	320
2005	*	*	*	*	*
2006	299	286	294	302	*
2007	306	272	291	307	*
2008	310	284	293	311	*
2009	306	287	292	295	*
2010	ND	ND	ND	ND	ND
Sodankylä					
2001	289	270	279	*	*
2002	*	268	273	275	287
2003	286	267	279	287	311
2004	288	280	281	288	307
2005	291	269	283	*	*
2006	296	264	264	288	*
2007	282	272	276	281	*
2008	296	267	272	284	302
2009	277	262	271	273	279
2010	282	281	281	290	298
Kenttärova					
2001	ND	ND	ND	ND	ND
2002	ND	ND	ND	ND	ND
2003	288	266	271	286	291
2004	279	256	281	282	292
2005	*	*	*	*	*
2006	290	266	270	280	292
2007	278	264	280	280	305
2008	287	279	287	287	298
2009	*	269	277	279	293
2010	ND	ND	ND	ND	ND

Doy: Day of year.
ND: No data available.
* Undefined due to insufficient data.

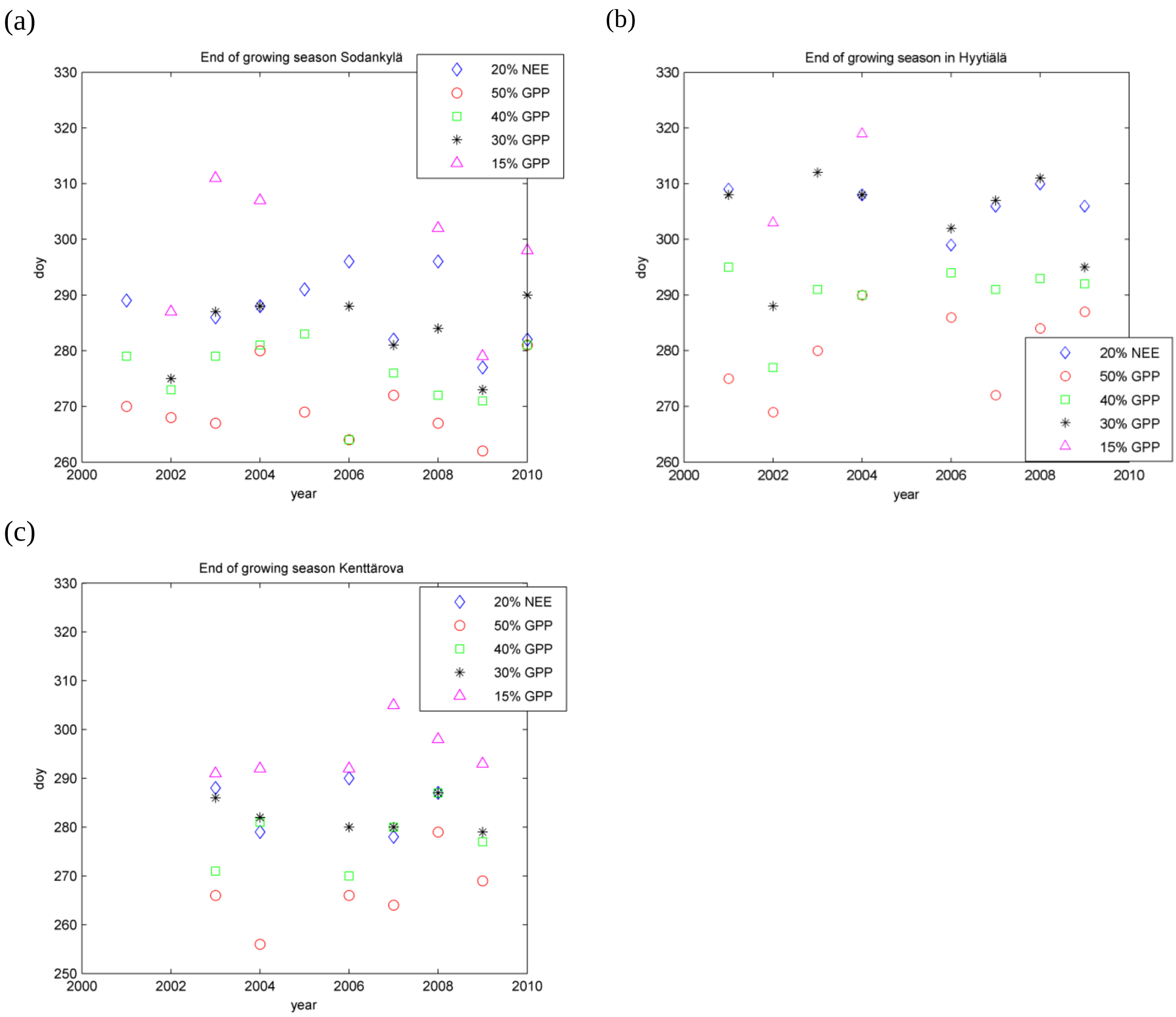

Figure 1. Phenological indicators for the end of growing season in coniferous forest sites from CO_2 flux measurements: (a) Sodankylä; (b) Hyytiälä; (c) Kenttärova.

Phenological observations of trees were compiled by the Finnish Forest Research Institute (METLA). Details on phenological observations are given in deliverable "Action 5 – In situ data collection and processing by SYKE" (30/11/2009).
The phenophase end of height growth (BBCH39 (Meier, 1997)) of Scots pine (*Pinus sylvestris*) in Parkano and of Norway spruce (*Picea abies*) in Pallasjärvi for years 2001-2010 were used in this report.

Extraction of phenological events from satellite observations in coniferous forest

Seasonal vegetation peak

The day with maximum NDVI in each year was extracted from linearly interpolated daily NDVI time-series as indicator for the seasonal vegetation growth peak in coniferous forest.

End of growing season

We used the descending inflection point of a double logistic function fitted to the NDVI time-series as satellite-derived end of season indicator for coniferous forest.

Furthermore, we evaluated the possibility to use NDVI threshold values for the determination of end of season phenological indicators from NDVI. NDVI was transformed according to White et al. (1997):

$$NDVI_{ratio} = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \qquad (1)$$

where $NDVI_{ratio}$ is the output ratio, ranging from 0–1, NDVI is the daily NDVI, $NDVI_{max}$ is the multi-year NDVI maximum and $NDVI_{min}$ is the site-based mean dry-snow-NDVI.

Comparisons of satellite-derived estimates with *in situ* observations

Function fitted NDVI time-series are shown in conjunction with phenological indicators from CO_2 flux measurements in Figure 2. The 50% GPP indicator showed correspondence with the mid-point of the descending part of the double logistic function fitted to the NDVI time-series at sites Hyytiälä and Kenttärova for year 2009 (Figure 2 a,b). The other GPP based phenological indicators (40% GPP, 30% GPP, 15% GPP and 20% NEE) occurred later. In Sodankylä flux-based phenological indicators 50% GPP, 40% GPP and 20% NEE, were observed at the same time in year 2010 and seemed to occur when the mid-point of the fitted NDVI profile was already exceeded. The date of 30% GPP was observed in that specific year later than the 20% NEE indicator in contrast to observations for year 2009 in Hyytiälä (see also Figure 1 for sequence of CO_2 flux-based phenological indicators).
NDVI time-series for our test sites were in general characterised by very few observations in autumn (Figure 2, black circles) due to cloud cover and low sun elevation, which hindered in many cases a good description of the decrease of NDVI in autumn from its almost stable summer level to its winter level (which is fixed here at the mean dry-snow NDVI) and therefore influences as well the accuracy of the definition of the satellite-derived end of season indicator.

(a)

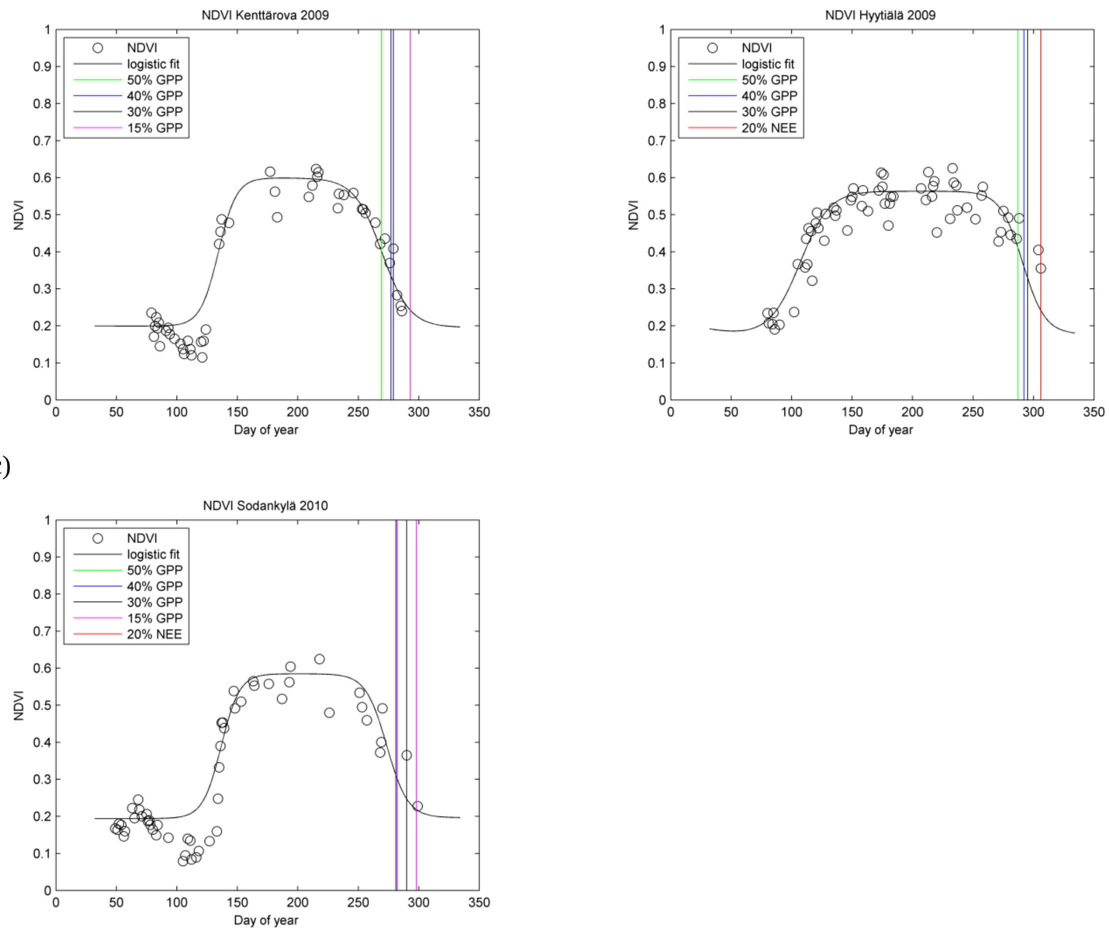

Figure 2. NDVI time-series and fitted logistic functions overlaid with phenological indicators (vertical lines) from CO_2 flux measurements for year 2009 in (a) Kenttärova, (b) Hyytiälä and 2010 in Sodankylä (c).

In the following, the correspondence between NDVI-based indicators determined for 27 site-years and CO_2 flux-based indicators was assessed. As illustrated in Figure 3, results were very scattered and correlations with *in situ* indicators were low, but significant (at the 0.05 level) with coefficients of determination (R^2) ranging between 0.19–0.45. For the phenological indicators 20% NEE, 15% GPP and 30% GPP relationships were offset from the 1:1 line with earlier occurance of the NDVI-based indicator, which seemed to be even more pronounced for the Hyytiälä site in Southern Finland than for the northern sites Sodankylä and Kenttärova. Similar slopes of regression lines were observed for the other indicators 40% GPP and 50% GPP.

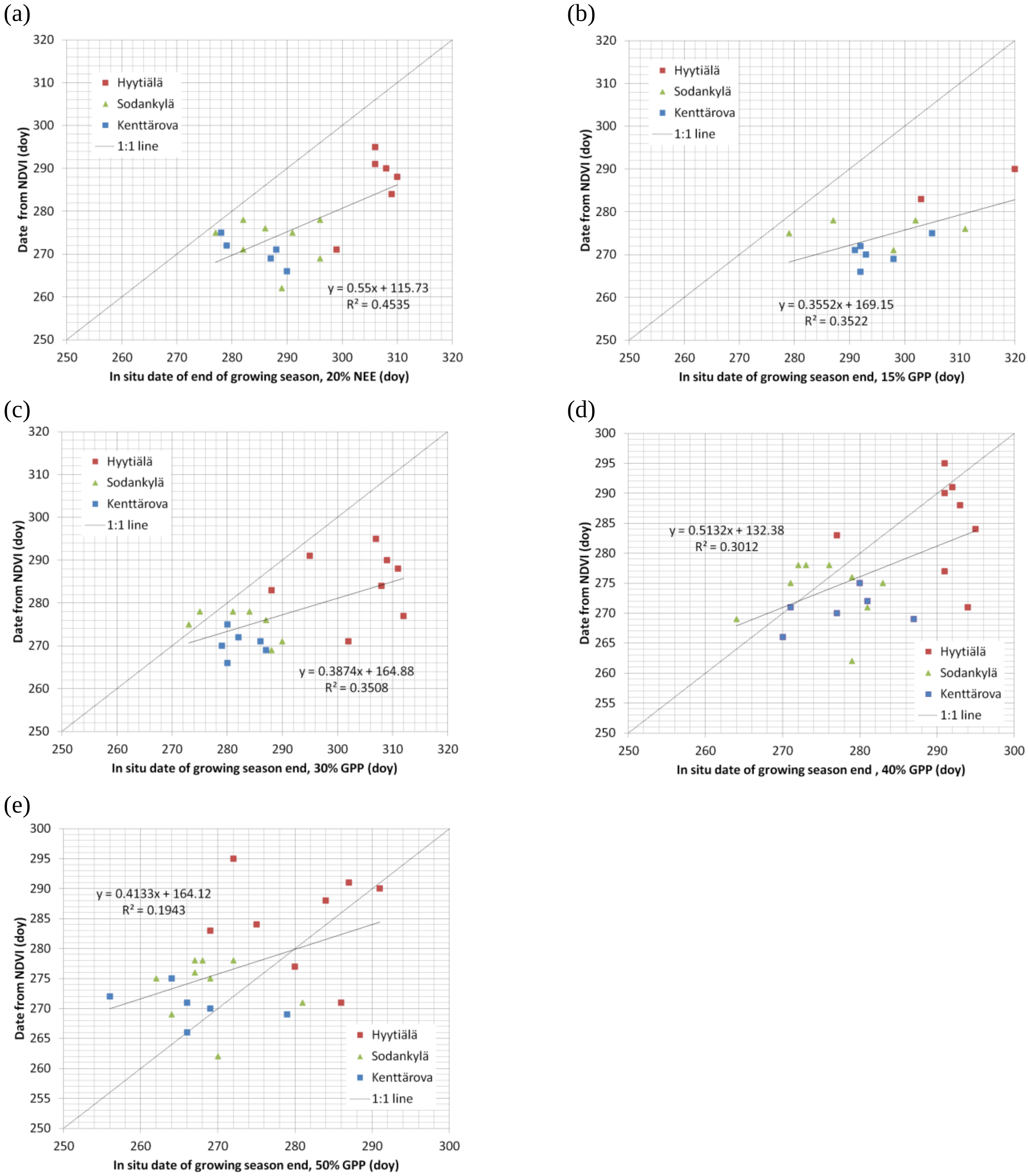

Figure 3. Comparison of *in situ* phenological indicators with estimates derived from NDVI time-series: (a) 20 % NEE; (b) 15% GPP; (c) 30% GPP; (d) 40% GPP; (e) 50% GPP. The end of growing season from NDVI was determined at the descending inflection point of a double logistic function fitted to the NDVI profile. Doy is day of year.

$NDVI_{ratio}$ values, which were obtained on the date of occurance of different *in situ* phenological indicators from CO_2 flux measurements, are shown in Table 3 for sites Sodankylä and Kenttärova. $NDVI_{ratio}$ ranged between 0.64-0.84 (mean 0.75) and 0.59-0.78 (mean 0.7) for indicators 50% GPP and 40% GPP, respectively. The indicator 20% NEE could only be assessed for few years at site Sodankylä due to missing data and ranged between 0.53-0.69. Large variations of $NDVI_{ratio}$ for indicators 50% GPP and 40% GPP hinder the application of one simple threshold for the determination of these events from NDVI time-series.

SYKE ILMATIETEEN LAITOS METEOROLOGISKA INSTITUTET FINNISH METEOROLOGICAL INSTITUTE

Table 3. Maximum NDVI and $NDVI_{ratio}$ at time of phenological indicators from CO_2 flux measurements in Sodankylä and Kenttärova. Only years with sufficient NDVI data quality for the second half of the year were included.

	NDVI maximum	Day of NDVI maximum (doy)	$NDVI_{ratio}$ 50% GPP	$NDVI_{ratio}$ 40% GPP	$NDVI_{ratio}$ 20% NEE
Sodankylä					
2002	0.6	213	0.81	0.78	*
2007	0.6	198	0.75	0.67	0.53
2008	0.59	199	0.78	0.75	*
2009	0.60	206	0.84	0.78	0.69
2010	0.6	194	0.69	0.69	0.69
Kenttärova					
2003	0.64	199	0.73	0.73	*
2005	0.67	215	*	*	*
2006	0.66	209	0.64	0.59	*
2007	0.66	196	0.74	*	*
2009	0.64	215	0.73	0.67	*

Doy: day of year.
* Undefined due to insufficient data,

The day when NDVI had its maximum in summer was compared with field observations of end of height growth in Hyytiälä and Kenttärova (Figure 4). Mean maximum NDVI for all site-years (N=15) occurred on day 194 (13^{th} of July) compared to day 191 (19^{th} of July) for phenological observation of end of shoot elongation. As illustrated in Figure 4, correlation between the two indicators is low. For individual sites, NDVI maximum was observed in average six and two days after end of height growth for Pallasjärvi and Parkano, respectively. The Pallasjärvi site is located in close distance, but in lower elevation (90 m) than the Kenttärova site and therefore phenological development in Kenttärova may lag behind observations in Pallasjärvi. Observations of end of growth of pine are a few days delayed in Parkano compared to Hyytiälä (data by Pasi Kolari, Helsinki University not shown).

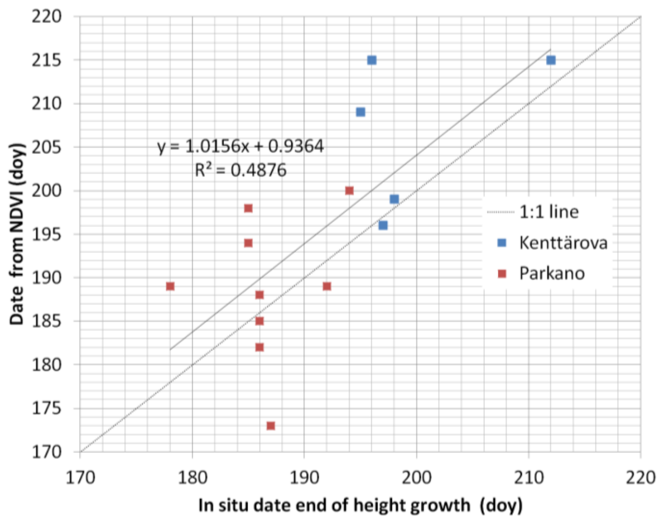

Figure 4. Comparison of day of maximum NDVI with phenological observations of end of height growth for sites Hyytiälä and Kenttärova. Phenological observations of pine trees from Parkano and of spruce trees in Pallasjärvi were used for sites Hyytiälä and Kenttärova, respectively.

Conclusions

In this report, date of vegetation peak and end of season was determined from NDVI time-series and correspondence between satellite-estimates with *in situ* observations was assessed for three evergreen coniferous sites in Finland. The descending inflection point of a double logistic function fitted to NDVI time-series served as measure for the end of growing season and revealed low correlations with phenological indicators describing different levels of GPP decrease in autumn at CO_2 flux measurements sites. NDVI-based end of growing season estimates can therefore not be used for the evaluation of model results (action 6) at this stage. The data quality of NDVI time-series was in most cases low, especially at the end of autumn, due to low sun elevation and long periods with cloud cover. A fixed value of NDVI was used here to fill values in winter and to allow a more stable fitting of a logistic function to NDVI time-series. An observation-based yearly date when ground starts to be snow covered instead of a region-wise statistical mean may improve fitting results. Our results indicated further that simple NDVI threshold values seem not to be applicable for extraction of the end of growing season for evergreen coniferous sites. Maximum NDVI occurred in average three days after phenological observations of end of pine growth at two coniferous sites.

References

Delbart, N., Kergoat, L., Le Toan, T., L'Hermitte, J., Picard, G., 2005. Determination of phenological dates in boreal regions using normalized difference water index. Remote Sensing of Environment 97, 26-38.

Härmä, P., Teiniranta, R., Törmä, M., Repo, R., Järvenpää, E., Kallio, E., 2005. CLC2000 Finland: Final Report. Finnish Environment Institute, Geoinformatics and Land Use Division.

Jönsson, P., Eklundh, L., 2004. TIMESAT-a program for analyzing time-series of satellite sensor data. Computers & Geosciences 30, 833-845.

Karlsen, S.R., Tolvanen, A., Kubin, E., Poikolainen, J., Høgda, K.A., Johansen, B., Danks, F.S., Aspholm, P., Wielgolaski, F.E., Makarova, O., 2008. MODIS-NDVI-based mapping of the length of the growing season in northern Fennoscandia. International Journal of Applied Earth Observation and Geoinformation 10, 253-266.

Kimball, J.S., McDonald, K.C., Running, S.W., Frolking, S.E., 2004. Satellite radar remote sensing of seasonal growing seasons for boreal and subalpine evergreen forests. Remote Sensing of Environment 90, 243-258.

Meier, U. (Ed), 1997. BBCH-Monograph. Growth stages of mono- and dicotyledonous plants. Blackwell, Berlin.

Rauste, Y., Astola, H., Häme, T., Berglund, R., Sirro, L., Veijonen, T., Veikkanen, B., Kubin, E., Aulamo, O., 2007. Automatic monitoring of autumn colours using MODIS data. IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2007, Barcelona, Spain, pp. 1295-1298.

Richardson, A.D., Andy Black, T., Ciais, P., Delbart, N., Friedl, M.A., Gobron, N., Hollinger, D.Y., Kutsch, W.L., Longdoz, B., Luyssaert, S., Migliavacca, M., Montagnani, L., William Munger, J., Moors, E., Piao, S., Rebmann, C., Reichstein, M., Saigusa, N., Tomelleri, E., Vargas, R., Varlagin, A., 2010. Influence of spring and autumn phenological transitions on forest ecosystem productivity. Philosophical Transactions of the Royal Society B: Biological Sciences 365, 3227-3246.

Suni, T., Berninger, F., Vesala, T., Markkanen, T., Hari, P., Mäkelä, A., Ilvesniemi, H., Hänninen, H., Nikinmaa, E., Huttula, T., Laurila, T., Aurela, M., Grelle, A., Lindroth, A., Arneth, A., Shibistova, O., Lloyd, J., 2003. Air temperature triggers the recovery of evergreen boreal forest photosynthesis in spring. Global Change Biology 9, 1410-1426.

Thum, T., Aalto, T., Laurila, T., Aurela, M., Hatakka, J., Lindroth, A., Vesala, T., 2009. Spring initiation and autumn cessation of boreal coniferous forest CO_2 exchange assessed by meteorological and biological variables. Tellus B 61, 701-717.

White, M.A., Thornton, P.E., Running, S.W., 1997. A Continental Phenology Model for Monitoring Vegetation Responses to Interannual Climatic Variability. Global Biogeochem. Cycles 11, 217-234.