VULNERABILITY ASSESSMENT OF ECOSYSTEM SERVICES FOR CLIMATE CHANGE IMPACTS AND ADAPTATION (VACCIA)

ACTION 2: DERIVATION OF GMES-RELATED REMOTE SENSING DATA

DELIVERABLE 3: INDICATOR VALUES DERIVED FROM ESTIMATED TIME SERIES

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CONTENT

Indicator values estimated from derived time series

This deliverable is a direct continuation for the previous deliverables of VACCIA Action 2 (Remote sensing). The methods and work flows to derive filtered and interpolated/modeled time series of green vegetation rising (expressed with NDVI-index) and snow melt (SCA) from the years 2001-2008 were presented in the previous deliverables. Earth observation (EO) based time series were extracted for 5 different FinLTSER-site areas of interest (AOI) and separated to major land cover classes (agricultural areas, coniferous forests, broad leaved forests, mixed forests and peat land areas). Time series were filtered with standard methods and modeling was performed for the snow melt event and start of the growing season.

This document presents the methods for acquiring the indicative dates from the derived modeled time series i.e. 1) the start date of the snow cover melting, 2) the first snow free land date, 3) the date for green vegetation onset and 4) the date when green vegetation growth reaches its maximum. The length of the time period without snow or green vegetation was further calculated from the previous information. Results are presented for different land cover classes in five different areas of interest in Finland. Information on the seasonal dynamics in these ecosystems was specifically under interest for the project actions 7, 8, 10 and 12.

Description of Areas of interests

NDVI and SCA information from the years 2001-2008 were extracted for five drainage basins of different size in Finland (Figure 1). Time series were generated for the areas of interest (AoI) of FinLTER-sites of Lammi (Action 8), Lake Päijänne (Action 10), Lepsämänjoki agricultural (Action 7) and Northern LTSER (Action 12). Maps from the areas of interest with general land cover are presented in Figure 2.

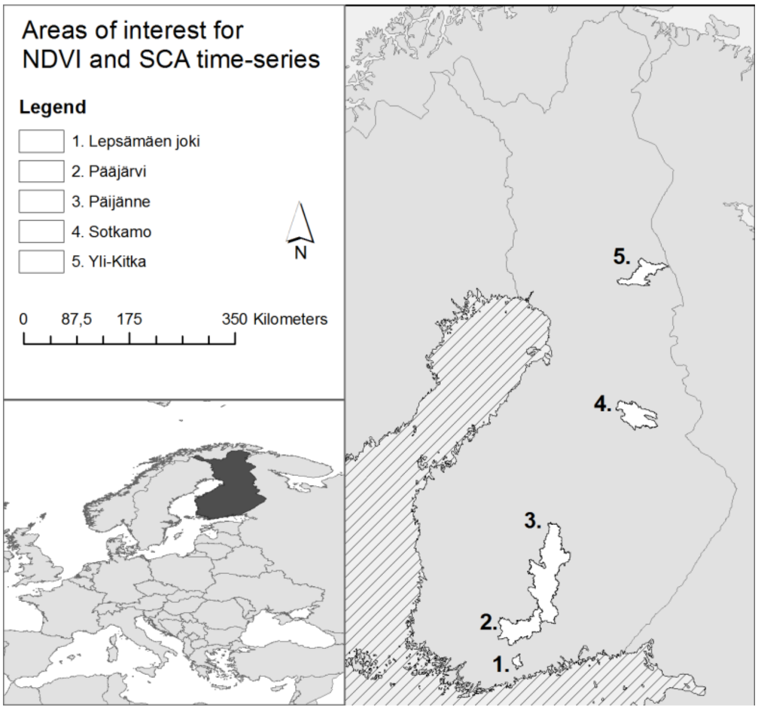


Figure 1. Areas of interest for NDVI and SCA time-series.

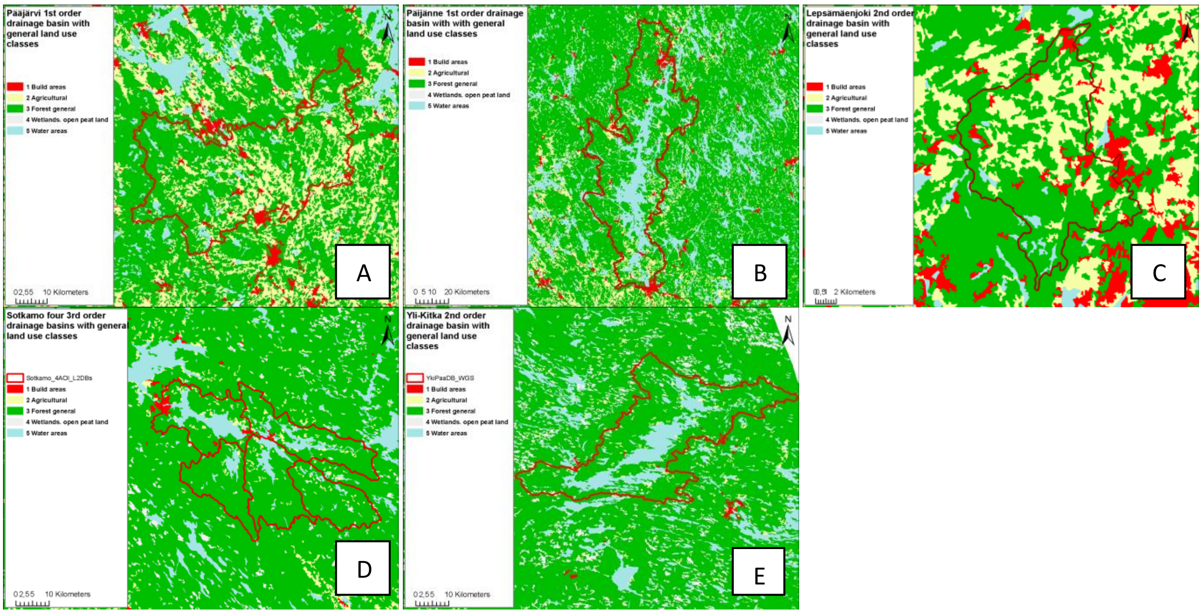


Figure 2. General land use in areas of interest (marked with polgygons in maps) for NDVI and SCA time series. Lake Pääjärvi 1st order drainage basin with area 3621 km^2 (A), Lake Päijänne 1st order drainage basin with area 9286 km^2 (B), River Lepsämäen joki 2nd order drainage basin with area 347 km^2 (C), four 3rd order drainage basin in Sotkamo area with area 3291 km^2 (D) and Lake Yli-Kitka 2nd order drainage basin with area 2856 km^2 (E).

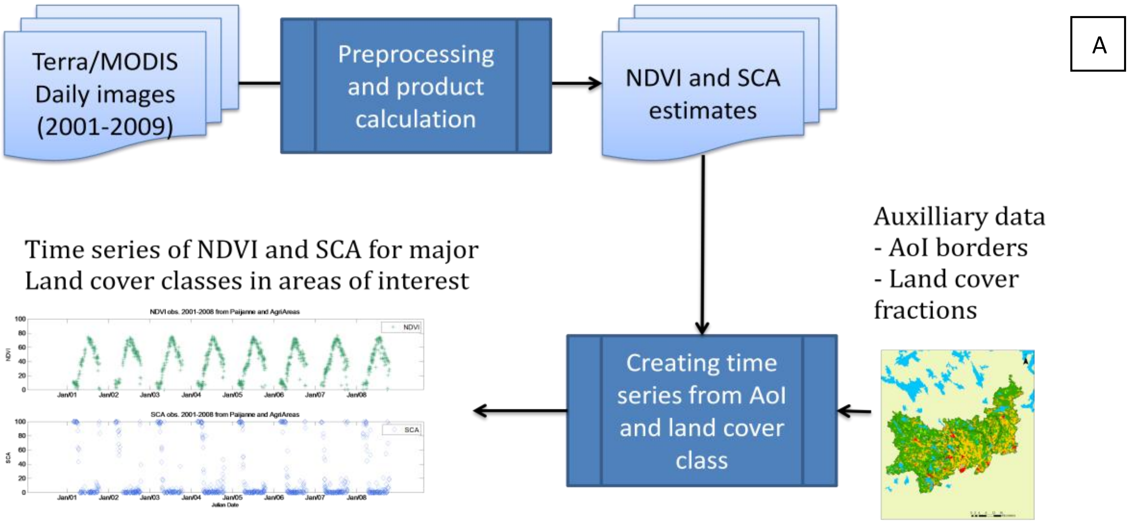
Each observation in time-series is a mean value from the applicable pixels of each land cover class. Estimation of NDVI and SCA is done in different spatial resolutions (250m and 500m, respectively) and therefore the number of pixels, i.e. sample size, varies according to the spatial resolution and land cover type fragmentation in areas of interest (table 2).

Table 1. Number of pixels with different land use class in areas of interest in 250 meter resolution (NDVI) and 500 meter resolution (SCA)

Area of Interest	# of pixels in agricultural areas in 250m/500m resolution	# of pixels in coniferous in forests areas 250m/500m resolution	# of pixels in broad leaved in forest areas 250m/500m resolution	# of pixels in mixed forest areas in 250m/500m resolution	# of pixels in Open peat land areas in 250m/500m resolution
Pääjärvi	3915/835	3496/734	49/12	803/137	110/32
Päijänne	1626/317	6687/1380	185/19	2793/461	105/25
Lepsämäenjoki	470/100	330/60	2/0	92/15	0/0
Sotkamo	148/28	2139/458	5/0	2456/419	80/13
Yli-Kitka	26/4	2819/575	5/1	860/133	127/28

METHODS

Methods and data sets used to derive interpolated and modeled EO based time series are provided in deliverables 1 and 2 of VACCIA/Action 2. The general process flow from raw satellite data to interpreted time series results are presented in figures 3A and 3B.



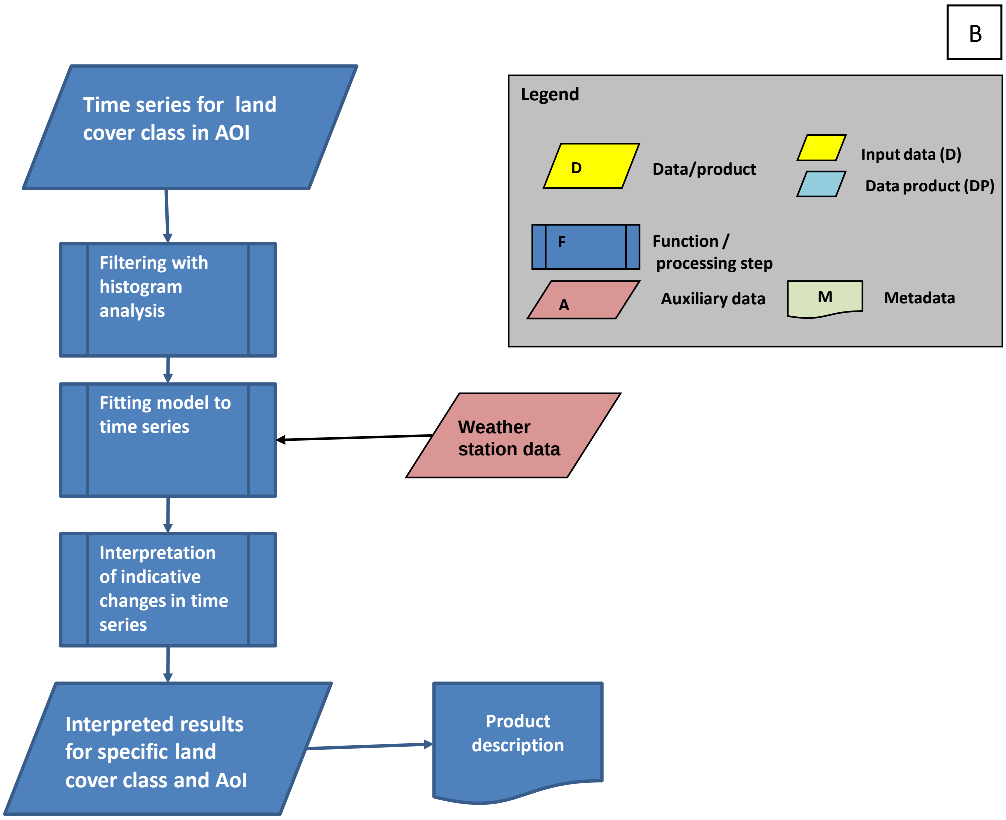


Figure 3. General process flow description for deriving time-series of NDVI and SCA from years 2001-2008 (A). The process flow for filtering, modeling and interpretation of time series (B).

Time series filtering

All time series of SCA and NDVI were filtered with the same method. Each observation in every time series is a daily mean value from a set of observations from a specific land cover type. Filtering was performed by eliminating observations i.e. pixels with values outside of two times the standard deviation around the mean of each set of daily observations. The number of observations, i.e. pixels with SCA or NDVI value, needed to exceed 10 in order to allow the calculation, otherwise observation was neglected.

Modeling and interpretation of the NDVI and SCA time series

Gaussian and sigmoidal functions were fitted to the filtered snow cover and NDVI time series, respectively. Synoptic weather station data was used as auxiliary information to help to set the parameters for the models.

Dates for the start and end of the melting period and, on the other hand, start of the green vegetation growth were estimated from the time series models. Finally, the lengths of the time periods without snow cover or green vegetation in years 2001-2008 were calculated for different land cover types at all the study sites.

Methods for the modeling and interpretation of NDVI time series

Gaussian, or similarly behaving sigmoidal, functions are often used to model phenological NDVI observations (e.g. Jönsson & Eklundh, 2002; Soudani et al., 2008). We used Gaussian function (Eq. 1) that was fitted to the NDVI time series from the drainage basins from the years 2001-2008.

$$\text{fNDVI}(t, r, a) = (1 - \exp(-\frac{t^2}{(r^2 * a)})) + n \qquad \text{eq. 1}$$

where, t is the time in days, r is time period in days in which the change occurs i.e. the range between minimum and maximum value, n is the NDVI or SCA value where NDVI time series starts increase in spring, *a* is a constant value. We used a = 1/3 according to (Chiles&Delfiner 1999). These parameters that define the shape of the gaussian model were chosen semi-empirically for each time series. First estimates for the parameter values were generated by minimizing the gaussian function in relation to the NDVI observations. Model performance was then visually checked and if needed, the parameter values were further manually adjusted to get the best possible fit.

Variety methods are used to derive phenological parameters from the remote sensing derived time series. For example, White et al. (1997) used the steepest increase in the NDVI value to determine the on set of green vegetation. Schwartz et al. (2002) used seasonal mid-point to moving average processed NDVI time series from the deciduous and mixed forests. Soudani et al (2008) concluded to use the inflection point in the sigmoidal curve fitted to deciduous NDVI time series for the determination of the green onset. Though methods for the determination of the green vegetation onset vary, the onset date is generally close to the point where NDVI curve reaches half of its maximum. This method was also used in Fisher and Mustard (2007) and we decided to use the same approach. Example of the performed analysis is presented in the figure 4.

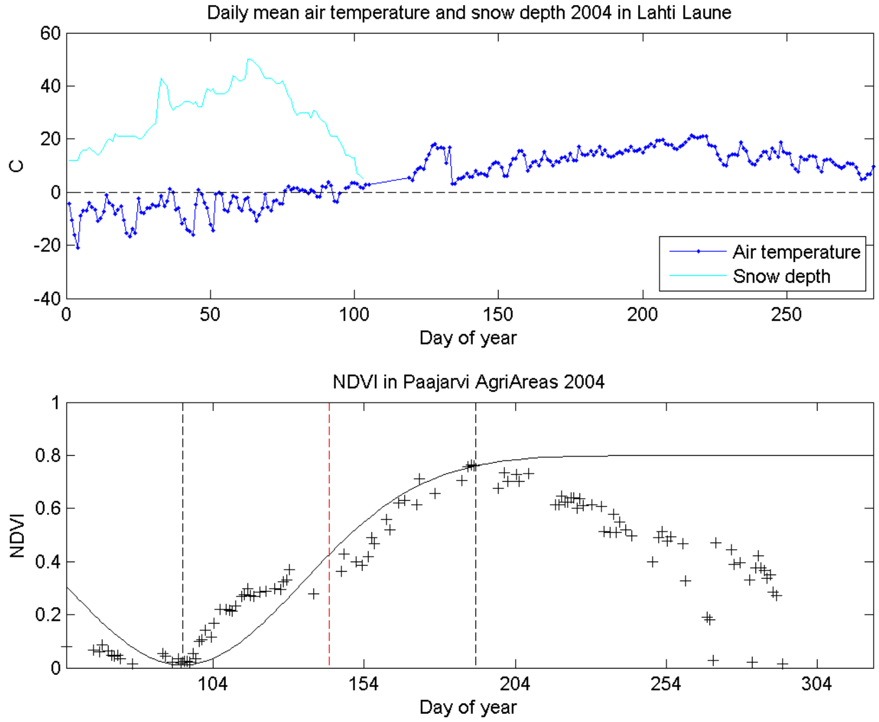


Figure 4. In the upper time series are shown the snow depth (solid line) and air temperature (dotted line) from the nearest weather station from the area of interest. In the time series below are EO based and filtered NDVI observations (crosses), fitted Gaussian model (solid line) and estimated interpretations from the NDVI model: minimum and maximum of NDVI (vertical and black dashed lines) and estimated green vegetation onset (dashed red line in the middle).

It needs to be noted that land cover type specific differences have been shown in phenological estimate methods from EO based time series, especially in the northern Europe deciduous forest (e.g. Karlsen et al.; 2008, Shutova et al., 2006). It is also argued that EO based NDVI time series from coniferous forests are disturbed by the deciduous understory (Spanner et al., 1990) and phenological estimates from these areas are not as useful as from e.g. agricultural areas (Bradley et al., 1994).

Methods for the modeling and interpretation of SCA time series

Similar time series analysis for the snow covered area was not found in the literature. Melting of snow is a variable process where melting is constantly suspended by colder periods and also falls of new snow. Melting itself, however, proceeds undeniable against the summer and the recession of snow coverage often follows a recurrent pattern. At the early stages of melting, accumulated layers of snow starts to recess slowly. This is followed by a rapid drop in snow coverage, when the daily mean temperature starts stay above zero. Recession in SCA is, however, constantly interrupted by colder periods and new snow fall, but these thin layers often melt quickly during the next warmer period. At the end of the melting period, the remaining snow hangs on the colder microclimates typically occurring in areas with icy soil or dense forests. This reasoning encouraged us to fit a sigmoidial function SCA time series (eq. 2.).

$$fSCA(t,a,b) = \frac{1}{1+\exp(\frac{a-t}{b})} \qquad \text{eq. 2}$$

Where *a* determines the position of inflection point i.e. the date where the melting rate starts to decrease after a faster drop, and *b* gives the rate of change. Temperature and snow dept data from the synoptic weather stations within or close to the AOI were used as auxiliary data to help in the parametrization of the models. The start and end of the melting period were then determined by using threshold values of 99% and 2%, respectively, to the SCA model (figure 5).

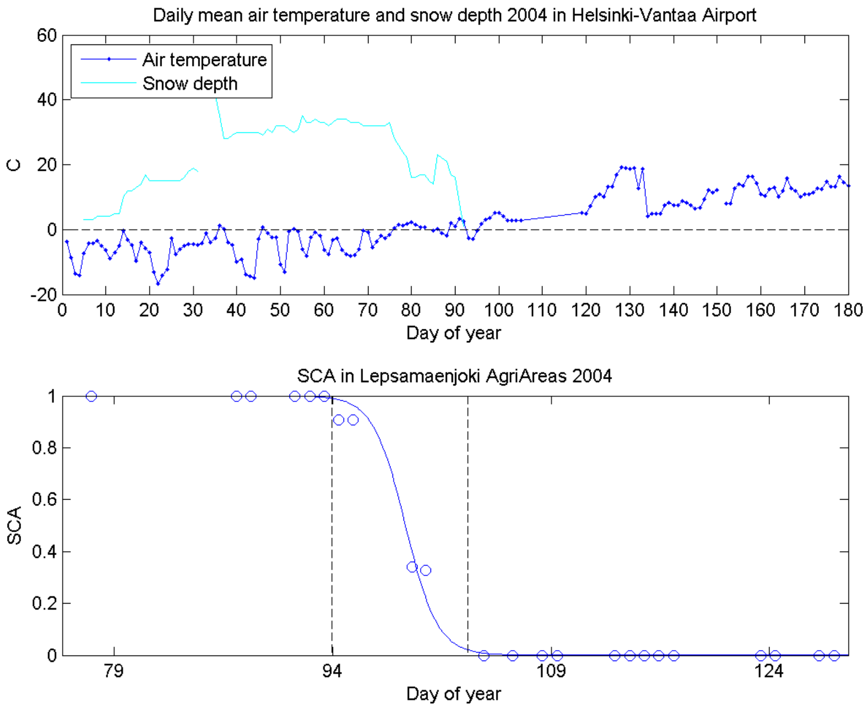


Figure 5. In the upper time series are show the snow depth (solid line) and air temperature (dotted line) from the nearest weather station from the area of interest. In the time series below are EO based and filtered SCA observations (circles), fitted sigmoidal model (solid line) and estimated interpretations from the SCA model: start and end of the melting period (vertical and black dashed lines).

Methods for determingin the length of time period without snow or green vegetation

Time period without snow or green vegetation was simply calculated as the difference between green vegetation on set date and first snow free day for different land cover class in areas of interest and years 2001-2008.

Results

Estimated indicator values from the SCA and NDVI time series from years 2001-2008 are presented in figures 6 – 19. Quality of all time series used to derive these results were visually rated to three classes, Ok, Ok- and Bad. Quality classification is presented in tables following each result figure. Quality class 'Bad' was used if changes in time series could not be reliably modeled due to the lacking number of observations, especially on time periods when changes occurred in time series. Status 'ok-' was given if time series was lacking observations in one or more of the dynamic periods, but the consistency of observations increased the reliability. Status ok was given for the time series with enough observations to fit the model reliably.

The lengths of time periods without snow cover or green vegetation for each land cover class and years 2001-2008 are presented in the table following the results from each area of interest.

While using these results, it needs to be taken into the consideration that the suitability of NDVI-index to express phenological events in different land cover types varies (see section: Methods for the modeling and interpretation of NDVI time series, page 7.).

LEPSÄMÄENJOKI DRAINAGE BASIN

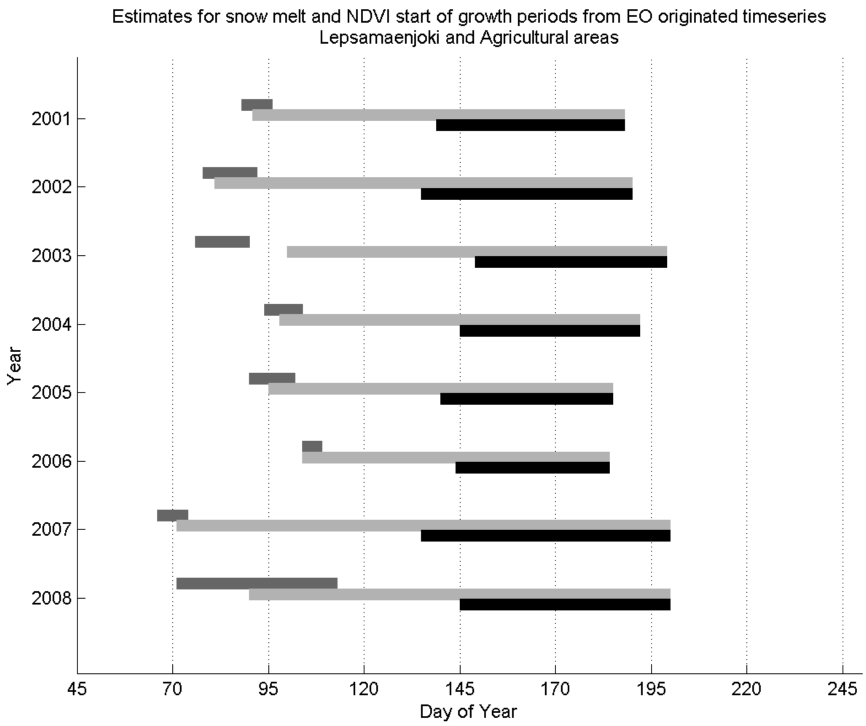


Figure 6. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for agricultural areas in Lepsämeäenjoki drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 2. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 6.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok	ok	ok	ok	ok-	ok-	ok	bad
QA NDVI	ok-	ok-	ok-	ok	ok	ok-	ok	bad

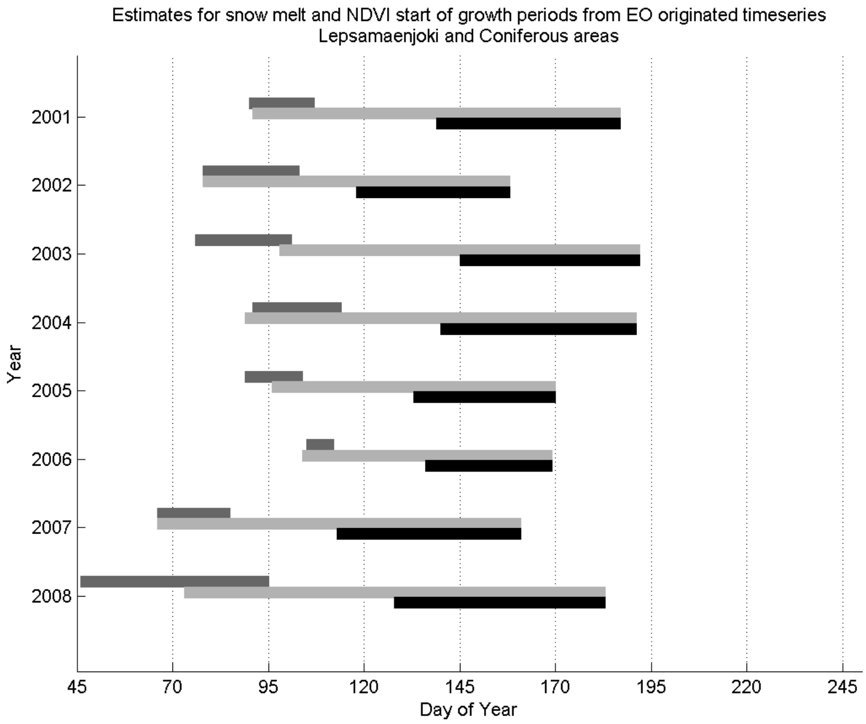


Figure 7. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for coniferous areas in Lepsämeäenjoki drainage basin. Information are derived from the filtered and modeled earth observation based time series.

Table 3. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 7.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok-	bad	ok	ok	ok	ok	ok	bad
QA NDVI	ok-	ok	ok	ok	ok	ok	ok	bad

Table 4. Estimated length of time period without snow or green vegetation (in days) for different land cover classes in Lepsämeäenjoki drainage basin and years 2001-2008. Result is overlined if quality assurance resulted class 'bad' in either SCA or NDVI model. Result is marked with bold, if quality status 'ok' was given for both of the models.

	2001	2002	2003	2004	2005	2006	2007	2008
Agricultural	43	43	59	**41**	38	35	**61**	~~32~~
Coniferous forest	32	~~15~~	**44**	**26**	**29**	**24**	**28**	~~33~~

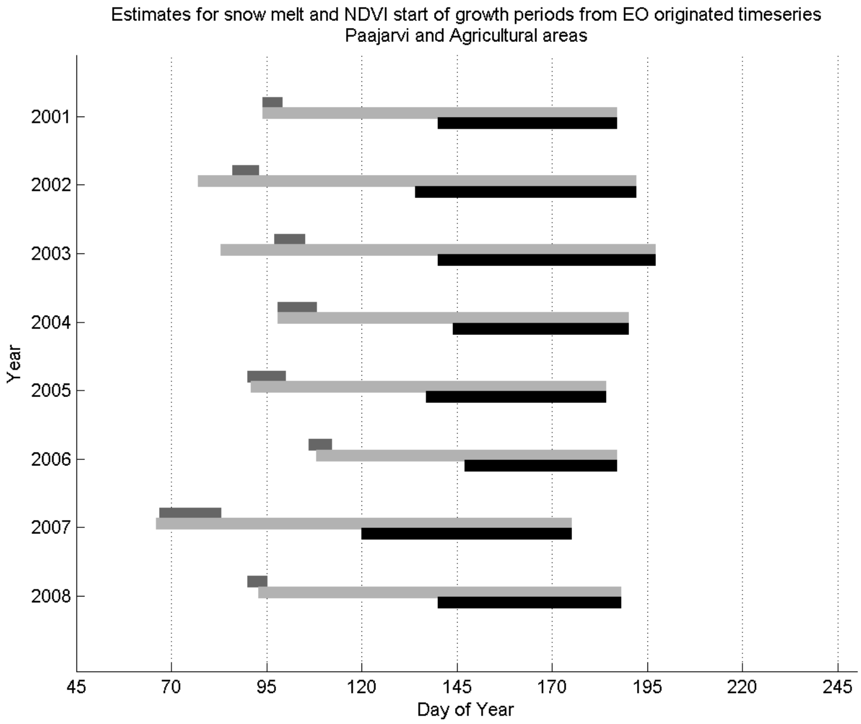


Figure 8. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for agricultural areas in Lake Pääjärvi drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 5. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 8.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok-	ok-	ok	ok	ok-	ok-	ok-	ok
QA NDVI	ok-	ok-	ok	ok	ok	ok-	ok-	ok

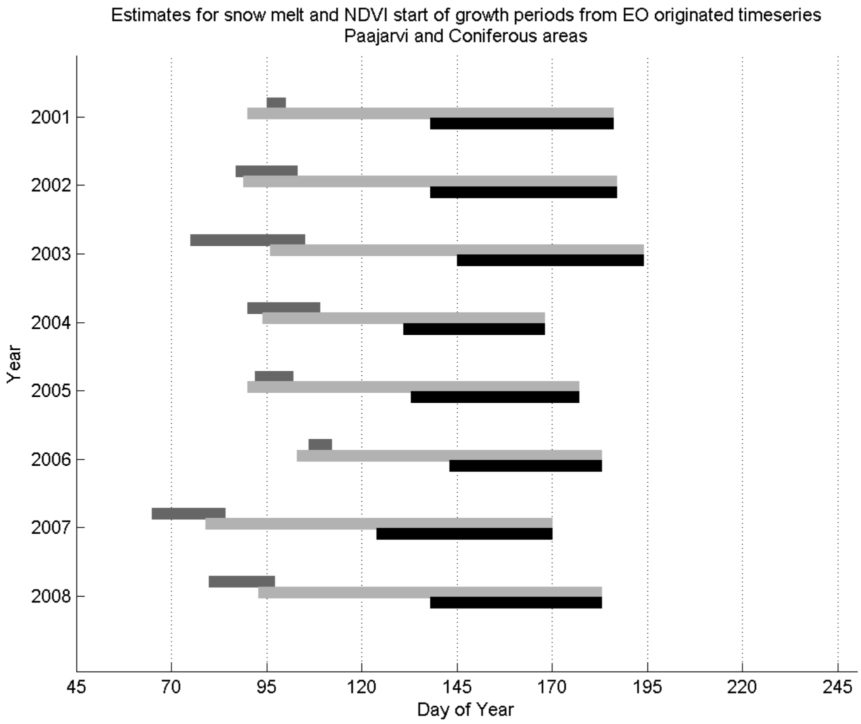


Figure 9. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for coniferous areas in Lake Pääjärvi drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 6. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 9.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	bad	bad	ok	ok	ok-	ok	ok-	bad
QA NDVI	ok-	bad	ok-	ok	ok	ok	ok-	ok-

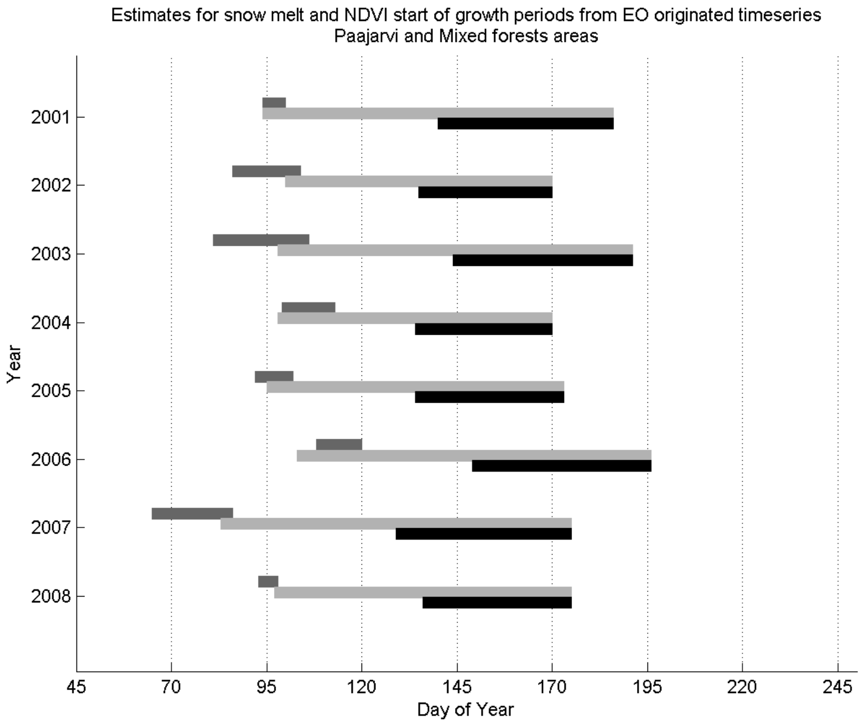


Figure 10. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for mixed forest areas in Lake Pääjärvi drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 7. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 10.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	bad	bad	ok	ok	ok-	ok	ok-	bad
QA NDVI	ok-	bad	ok	ok	ok-	ok	ok	ok-

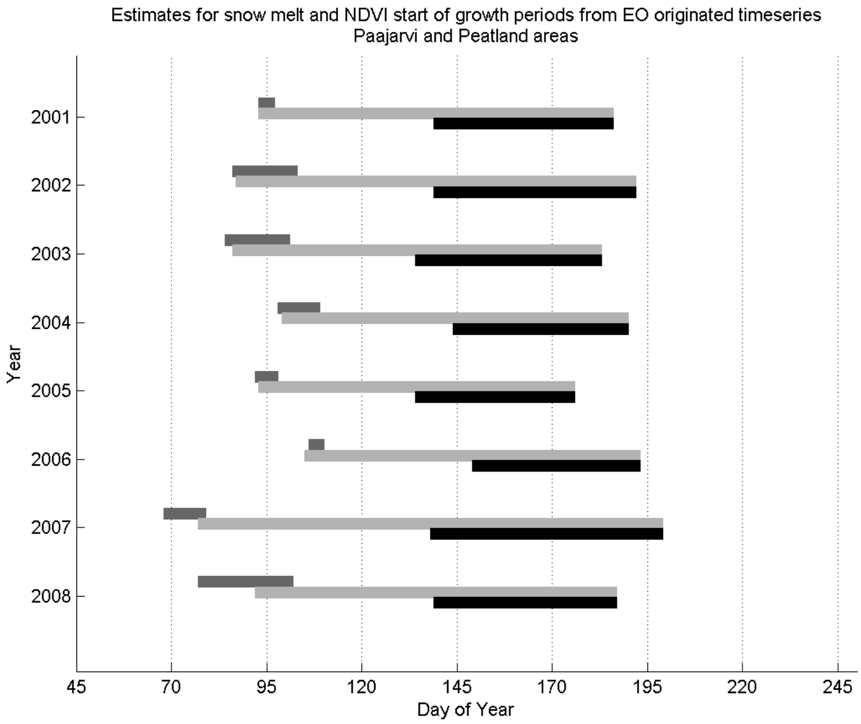


Figure 11. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for peatland areas in Lake Pääjärvi drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 8. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 11.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	bad	bad	ok	ok	ok	ok	ok-	ok-
QA NDVI	ok-	ok-	ok	ok-	ok-	ok-	ok	ok-

Table 9. Estimated length of time period without snow or green vegetation (in days) for different land cover classes in Lake Pääjärvi drainage basin and years 2001-2008. Result is overlined if quality assurance resulted class 'bad' in either SCA or NDVI model. Result is marked with bold, if quality status 'ok' was given for both of the models.

	2001	2002	2003	2004	2005	2006	2007	2008
Agricultural	41	41	**35**	**36**	37	35	37	**45**
Coniferous forests	~~38~~	~~35~~	40	**22**	31	**31**	40	~~41~~
Mixed forests	~~40~~	~~31~~	**38**	**21**	32	**29**	43	~~38~~
Peat land	~~42~~	~~36~~	**33**	35	36	39	59	37

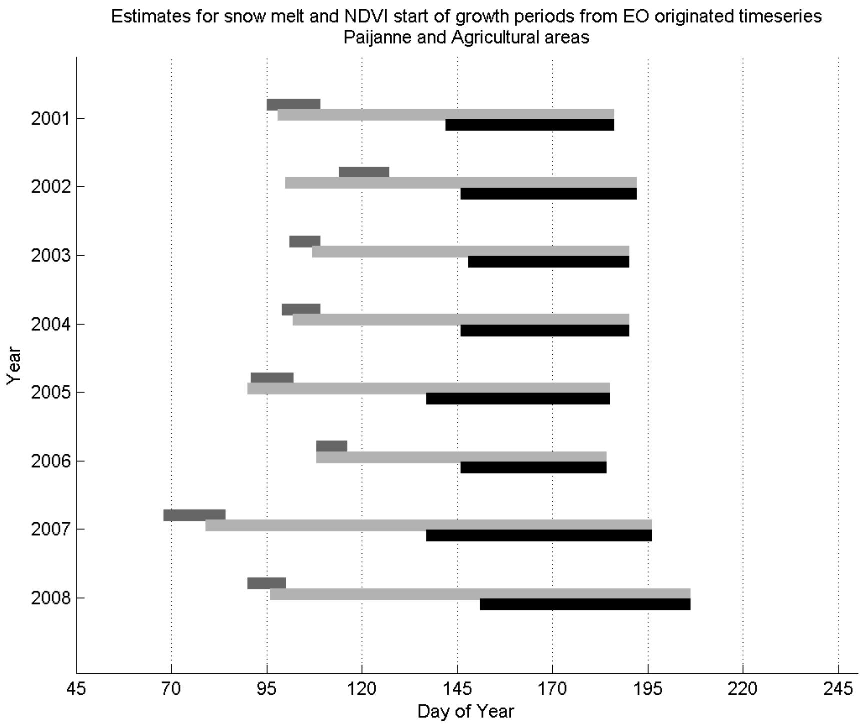


Figure 12. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for agricultural areas in Lake Päijänne drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 10. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 12.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok-	bad	ok	ok	ok	ok	ok	ok-
QA NDVI	ok-	ok-	ok	ok	ok	ok-	ok	ok-

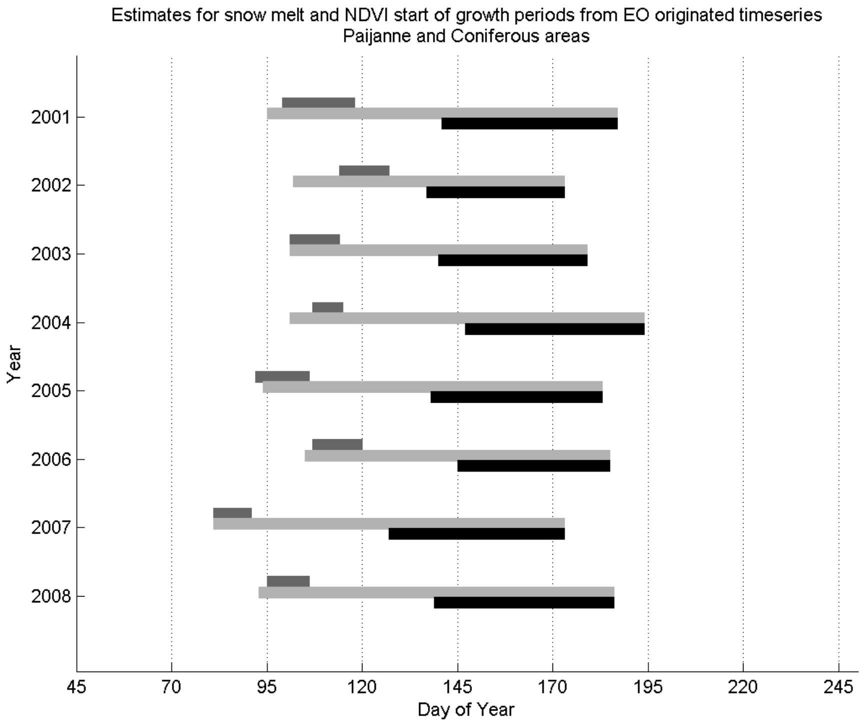


Figure 13. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for coniferous areas in Lake Päijänne drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 11. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 13.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok	bad	ok	ok	ok	ok	ok	bad
QA NDVI	ok-	bad	ok	ok	ok	ok	ok	ok-

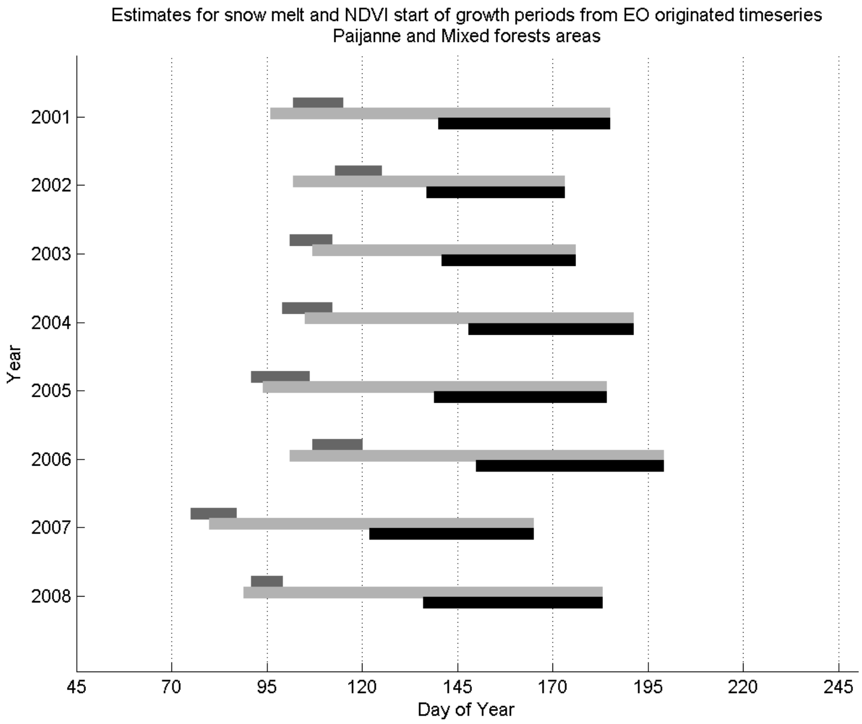


Figure 14. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for mixed forest areas in Lake Päijänne drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 12. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 14.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok-	bad	ok	ok	ok	ok	ok-	bad
QA NDVI	ok-	bad	ok	ok	ok	ok	ok	ok

Table 13. Estimated length of time period without snow or green vegetation (in days) for different land cover classes in Lake Päijänne drainage basin and years 2001-2008. Result is overlined if quality assurance resulted class 'bad' in either SCA or NDVI model. Result is marked with bold, if quality status 'ok' was given for both of the models.

	2001	2002	2003	2004	2005	2006	2007	2008
Agricultural	33	~~19~~	**39**	**37**	**35**	30	**53**	51
Coniferous forests	23	~~10~~	**26**	**32**	**32**	**25**	**36**	~~33~~
Mixed forests	25	~~12~~	**29**	**36**	**33**	**30**	35	~~37~~

SOTKAMO AREA

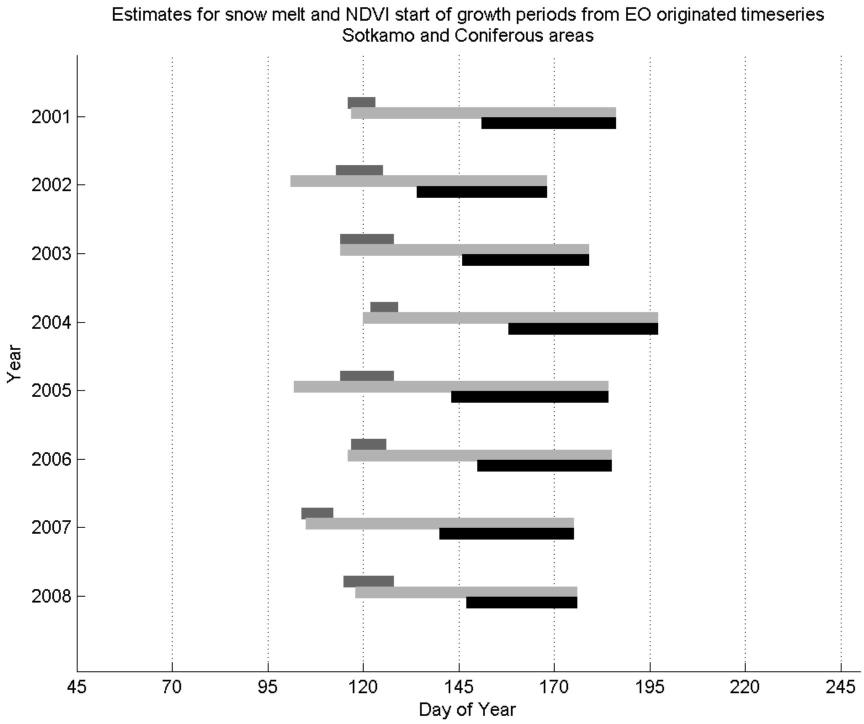


Figure 15. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for coniferous forest areas in Sotkamo. Information is derived from the filtered and modeled earth observation based time series.

Table 14. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 15.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok-	bad	ok	ok	ok-	ok	ok	ok
QA NDVI	ok-	bad	ok	ok	ok	ok	ok	ok

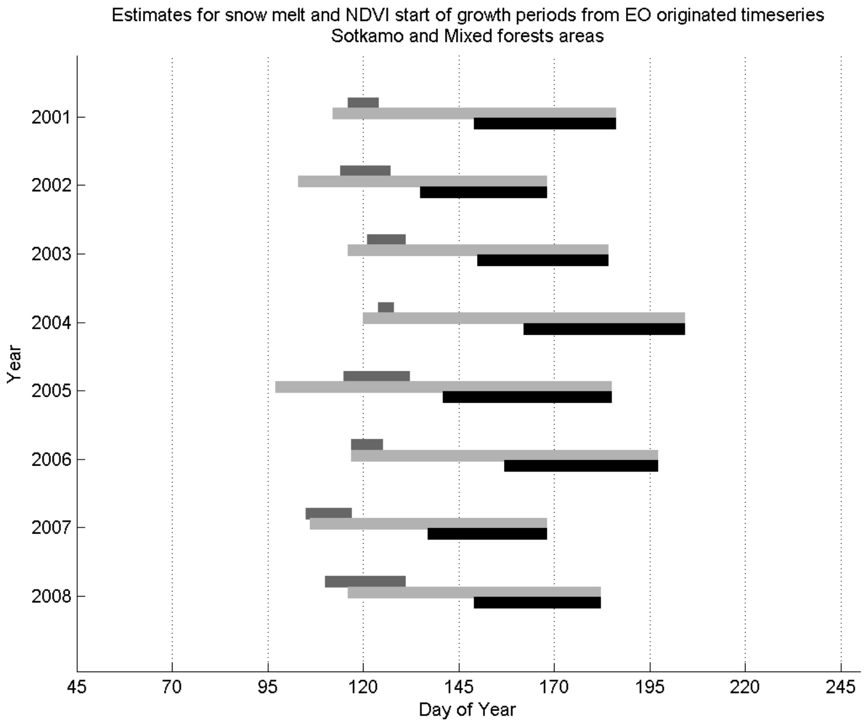


Figure 16. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for mixed forest areas in Sotkamo area. Information is derived from the filtered and modeled earth observation based time series.

Table 15. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 16.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok-	bad	ok-	ok	ok	ok	ok	ok
QA NDVI	ok-	bad	ok	ok	ok	ok	ok	ok

Table 16. Estimated length of time period without snow or green vegetation (in days) for different land cover classes in Sotkamo area and years 2001-2008. Result is overlined if quality assurance resulted class 'bad' in either SCA or NDVI model. Result is marked with bold, if quality status 'ok' was given for both of the models.

	2001	2002	2003	2004	2005	2006	2007	2008
Coniferous forests	28	~~9~~	**18**	**29**	15	**24**	**28**	**19**
Mixed forests	25	~~8~~	19	**34**	**9**	**32**	**20**	**18**

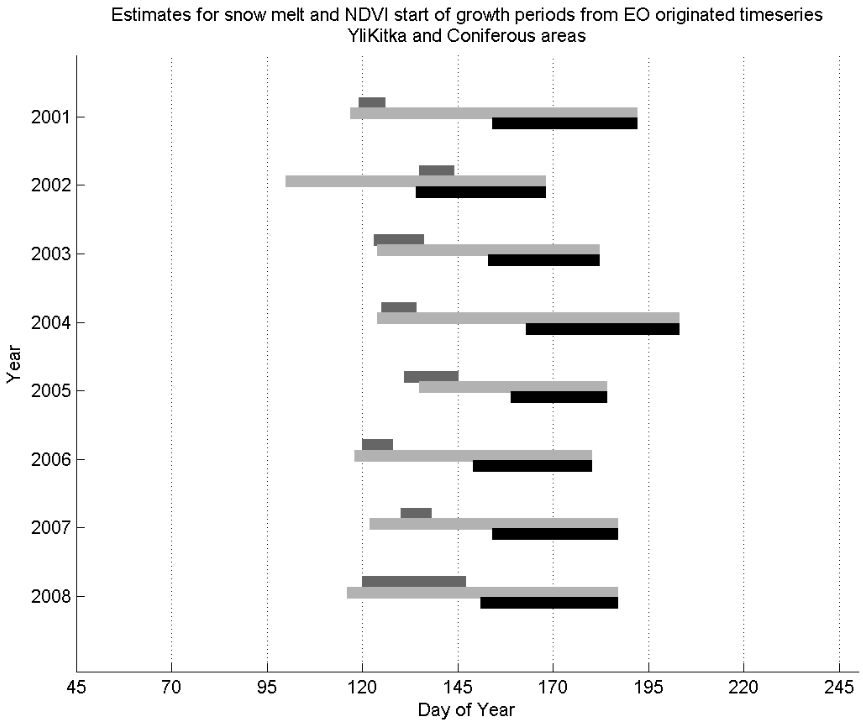


Figure 17. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for coniferous forest areas in Lake Yli-Kitka drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 17. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 17.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok-	bad	ok	ok	ok-	ok	ok	ok-
QA NDVI	ok-	bad	ok	ok	ok-	ok	ok	ok

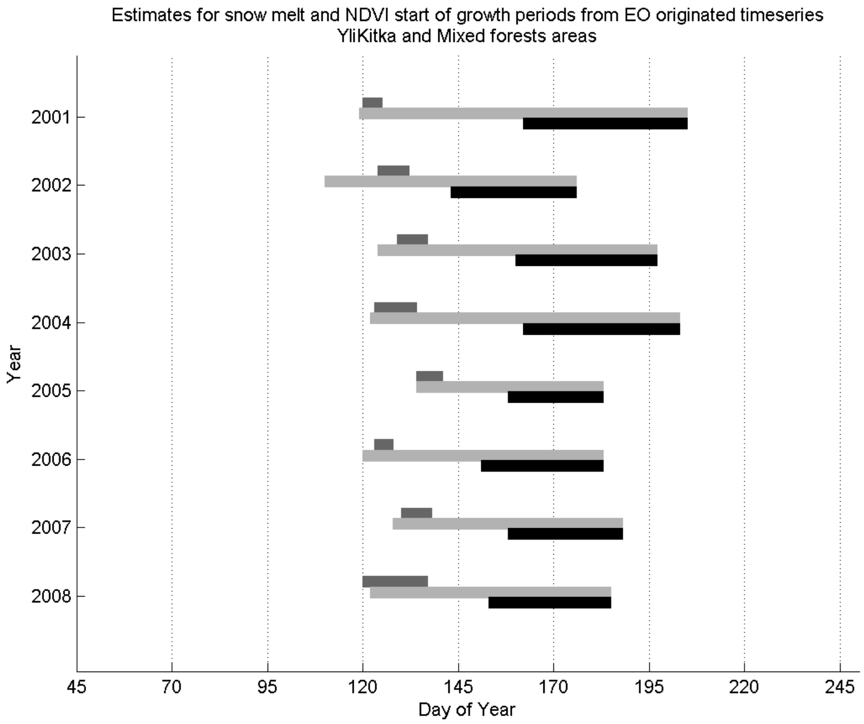


Figure 18. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for mixed forest areas in Lake Yli-Kitka drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 18. Quality assurance of SCA and NDVI time series used to derive the results in presented in figure 18.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok	bad	bad	ok	ok-	ok	bad	ok-
QA NDVI	ok	bad	ok	ok	ok-	ok	ok	ok

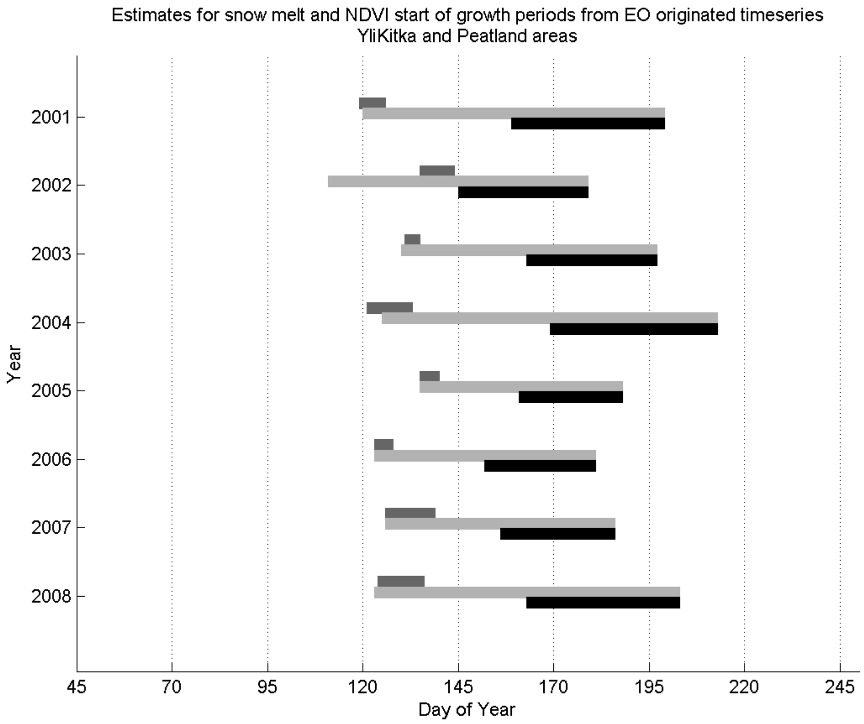


Figure 19. Estimates of snow melt period (dark grey line), time period from NDVI minimum to maximum (light grey line) and time period from the green on set to the NDVI maximum (black line) for peatland areas in Lake Yli-Kitka drainage basin. Information is derived from the filtered and modeled earth observation based time series.

Table 19. Quality assurance of SCA and time series used to the derive results in figure 19.

	2001	2002	2003	2004	2005	2006	2007	2008
QA SCA	ok	bad	bad	ok-	ok	ok	ok-	ok-
QA NDVI	ok-	bad	ok	ok-	ok-	ok	ok-	ok

Table 20. Estimated length of time period without snow or green vegetation (in days) for different land cover classes in Lake Yli-Kitka drainage basin and years 2001-2008. Result is overlined if quality assurance resulted class 'bad' in either SCA or NDVI model. Result is marked with bold, if quality status 'ok' was given for both of the models.

	2001	2002	2003	2004	2005	2006	2007	2008
Coniferous forests	28	~~10~~	**17**	**29**	14	**21**	**16**	4
Mixed forests	**37**	~~11~~	~~23~~	**28**	17	**23**	~~20~~	16
Peat land	33	~~1~~	~~28~~	36	21	**24**	17	27

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