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2nd progress report on filtered time-series (2001-2008)

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Action

Action 7: Methodological development and implementation

LIFE+ PROJECT NAME or Acronym

SNOWCARBO

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List of abbreviations

MODIS	Moderate Resolution Imaging Spectrometer
NDVI	Normalized Difference Vegetation Index
SCA	Snow Covered Area
VI	Vegetation Index
TSF	Temporal spatial filter
LAI	Leaf Area Index
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
REMO	Regional climate model

Summary

This report gives an update to deliverable "Progress report on filtered time-series (2001 - 2008)" (date 30/05/2010). It documents further work on gap-filling and smoothing of SCA and NDVI time-series. Furthermore, it shows processing scheme and preliminary results for spatial aggregation of time-series to the modelling grid for later validation of modelling results.

Introduction and objectives

Filtering and gap-filling of NDVI and SCA time-series were described in the first progress report on filtered time-series (see deliverable "Progress report on filtered time-series (2001 - 2008)".

This second report concentrates on improvements made to methods described in the first report and further developments including (i) comparison of time-series filtered with improved cloud masks with time-series filtered with previous cloud-masking algorithm version; (ii) further work on gap-filling of SCA time-series during snow melting period; (iii) further work on smoothing on NDVI time-series and (iv) spatial aggregation of time-series to resolution of modelling grid.

Data sets

MODIS time-series

MODIS NDVI and SCA time-series used here are described in detail in report "1st EO document (years 2001 – 2008)" (date 30/11/2009).

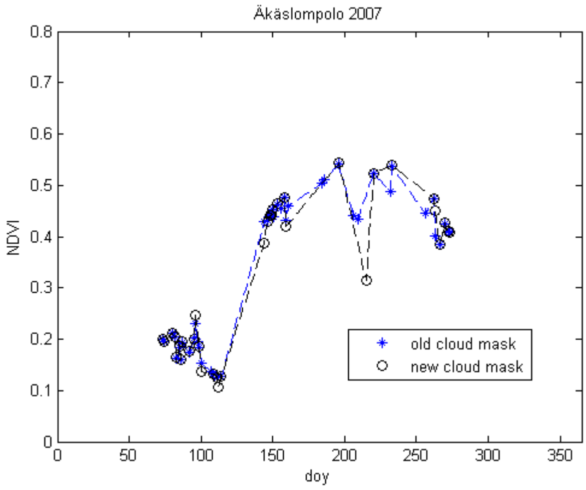
Land cover information

Fraction of land cover classes within each MODIS pixel (0.0025 and 0.005 degrees resolution) was calculated from CORINE Land Cover 2000 for Finland. Land cover fractions will be used for the spatial aggregation of time-series to the modelling grid.

Updated cloud filtering algorithm

The cloud filtering algorithm was updated in action 3 (see deliverable "2nd EO-data document (years 2001 -2010" (date 30/11/2010)) and applied to MODIS products from year 2007.

Extracted time-series from different test sites, filtered with new cloud-masking algorithm, are shown in comparison with time-series obtained with previous version of cloud-masking algorithm. Results indicate few changes in NDVI temporal profiles due to updated cloud algorithm. These changes occur mainly in summer.



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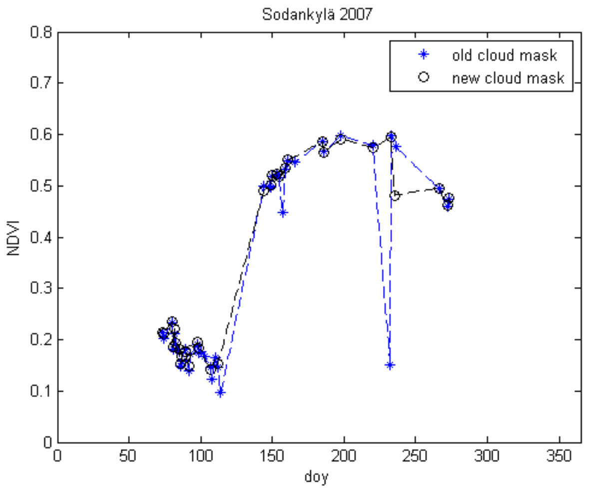

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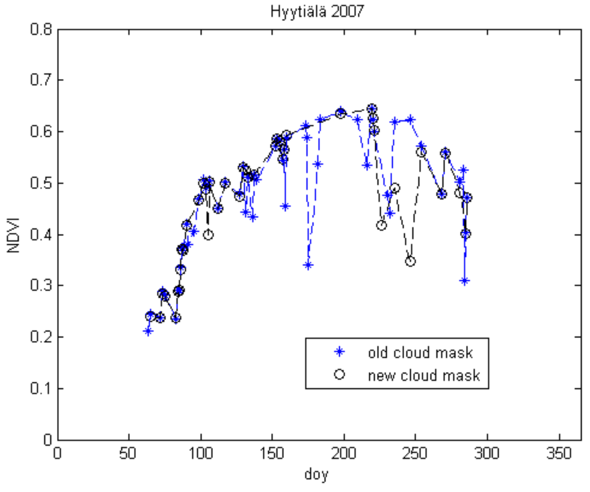

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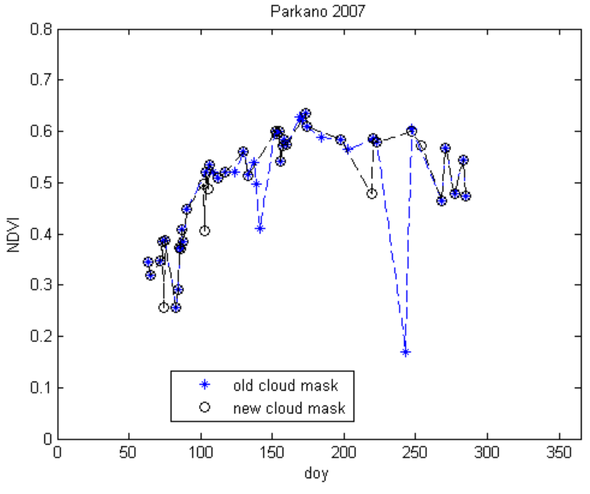

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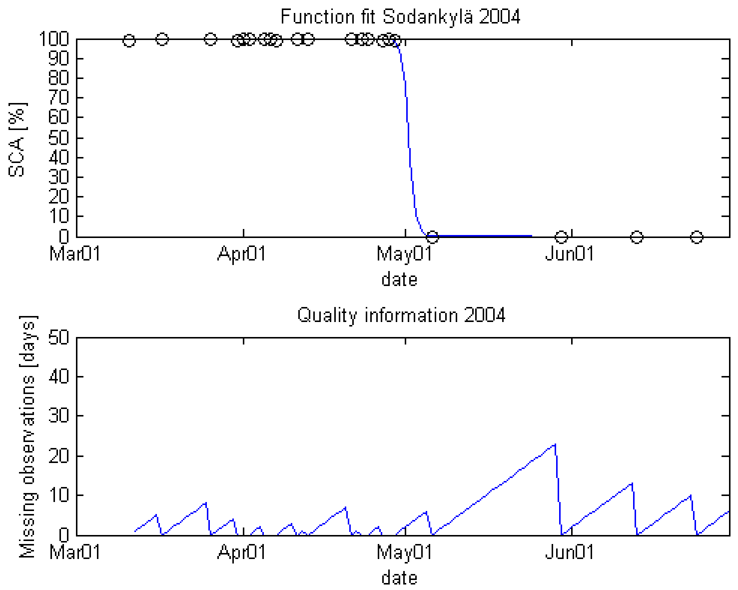
Figure 1. Comparsion of NDVI temporal profile for year 2007 using old (blue star) and new cloud-masking algorithm (black circle) for different test sites in Finland, (a) Äkäslompolo, (b) Sodankylä, (c) Hyytiälä and (d) Parkano.

Gap-filling of SCA time-series

SCA time-series for the northern boreal and mid-boreal region were smoothed and gap-filled using simple sigmoid function (see "Progress report on filtered time series (2001-2008)" (date 30/05/2010)). Interpolation is done for the period from February to July for each year. Quality information was added to daily values, giving a cloud-persistence count number, that means the number of consecutive days of cloud obscuration or missing data since last view of the surface. The approach follows Hall et al. (2010) and is illustrated in Figure 2.



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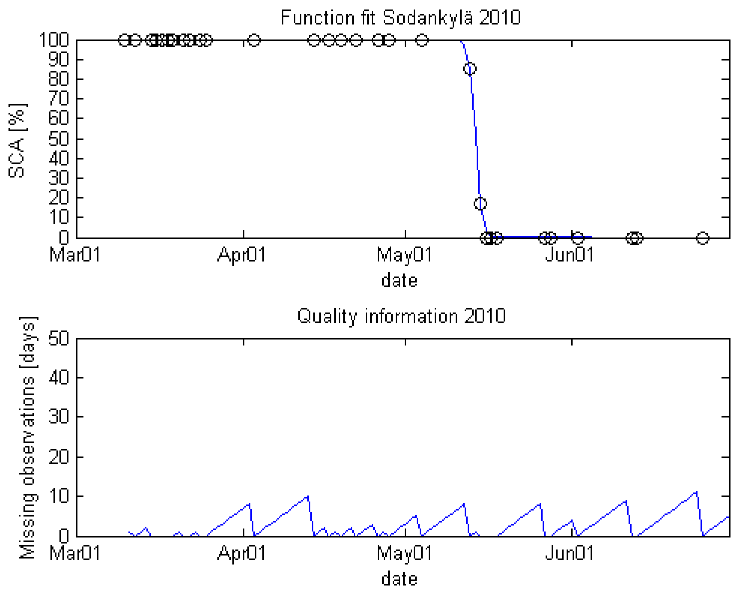

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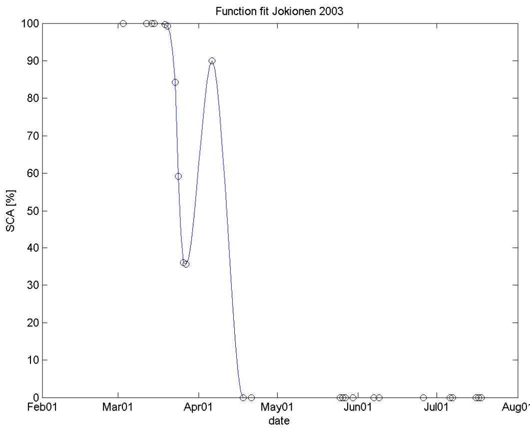
Figure 2. Interpolated SCA time-series at Sodankylä and number of days with missing observations for the period from March to end of June for years (a) 2004 and (b) 2010. SCA time-series were interpolated using a sigmoid function.

In order to interpolate cloud-filtered SCA time-series for areas with non-permanent snow cover in winter (for example in southern boreal region in some years and southern areas of SnowCarbo study area), monotone piecewise cubic interpolation was applied. The method was developed by Fritsch & Carlson (1980) to produce 'visually pleasing' monotone piecewise cubic interpolants and the approach was applied by Dozier *et al.* (2008) for interpolation of smoothed fractional snow cover. The MATLAB (version 7.8) function *pchip* was used for computation of monotone piecewise cubic interpolation.
Results are shown for different years for the meterological station Jokionen.
Missing observations due to cloud cover are more critical in areas or specific years where snow cover is not permanent during winter. Snow observations at meterological station may serve as auxiliary data for the delineation of such areas for each year. The use of longer temporal compositing period (for example weekly or 10 day composits of average snow cover) may be more adequate in such conditions.



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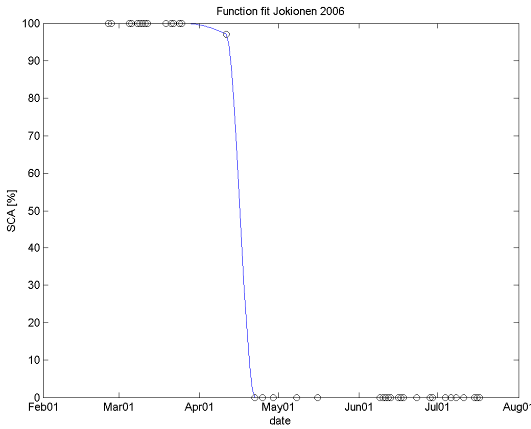

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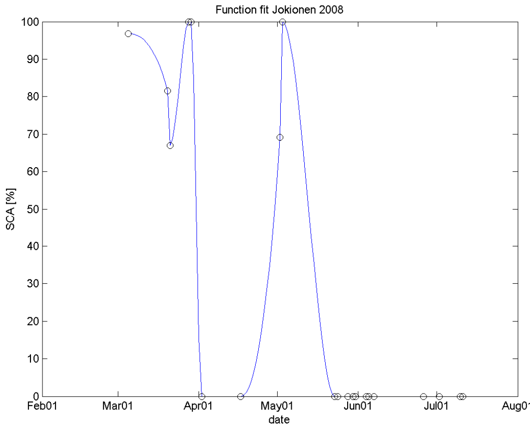

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Figure 3. Spline interpolated time-series at Jokionen for years (a) 2003, (b) 2004 and (c) 2008.

Smoothing of NDVI time-series

Comparison of NDVI temporal profiles in spring with $C0_2$-flux-measurement-derived beginning of the growing season for coniferous forest, indicated that asymmetric Gaussian function or double logistic function fitting are not suitable for later extraction of this event from the NDVI profiles (see illustration in Figure 4 and deliverable action 7 "Progress report on extracted features (2001 -2008)"(date 31/08/2010)). Therefore, adaptive Savitzky-Golay

(1964) filtering was applied to daily interpolated NDVI time-series from coniferous forest sites. The algorithm is implemented in TimeSat software, version 2.3 (Jönsson and Eklundh, 2004). Figure 5 illustrates one example for the application of adaptive Savitzky-Golay filtering for Sodankylä.
The method was applied for smoothing of NDVI profiles from coniferous forest for determination of beginning of the growing season for different years in Finland (see deliverable action 9 "Preliminary progress report").

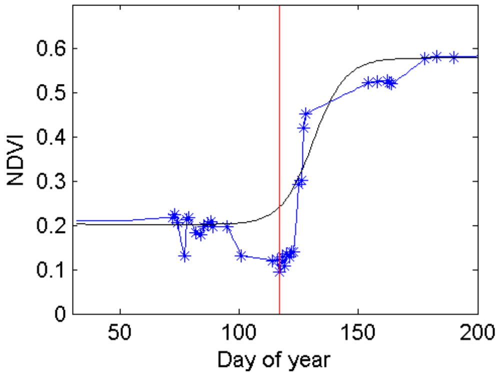

Figure 4. NDVI temporal profile at Sodankylä for the year 2006. Original NDVI values are shown as blue stars, linear interpolated values ar given as blue line and fitted logistic function as black line. CO_2-flux-measurement-derived start of season is indicated with red line.

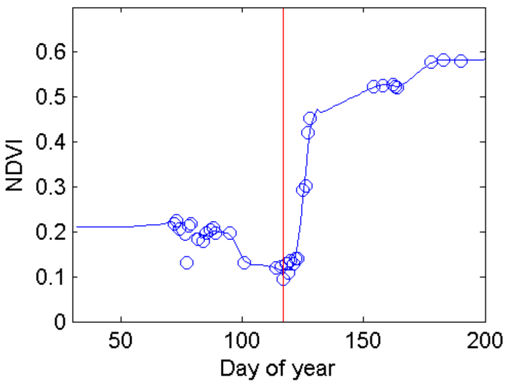

Figure 5. NDVI temporal profile at Sodankylä for the year 2006. Original NDVI values are shown as blue circles and smoothed interpolated values based on Savitzky-Golay filter are shown as blue line. CO_2-flux-measurement-derived start of season is indicated with red line.

Spatial aggregation of time-series to modelling grid

Time-series of SCA and NDVI or derived features (for example start of season) will be used as validation data for model outputs (action 6). This requires temporally and spatially continuous measurements as the same spatial resolution as the modelling grid.
Advanced filtering techniques have been developed for examples for the production of spatially and temporally continuous MODIS products (Moody *et al.*, 2005; Fang *et al.*, 2008; Gao *et al.*, 2008; Nightingale *et al.*, 2009).

Fang et al. (2008) developed temporal spatial filter (TSF) for 8-day MODIS LAI products in order to fill gaps and to improve quality of the product. The filter integrates both spatial and

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temporal characteristics for different plant functional types and consists in the following steps: (i) Temporal filling of gaps with multiyear-average of the same day based on the fact that pixels's multi-year variation is less than or similar to spatial variation within an ecosystem; (ii) in case of missing data over all years ecosystem curve fitting (Moody *et al.*, 2005) using MODIS continous fields products[1] is applied and; (iii) Combined temporal and spatial filter using results from the above steps as background and the observation value to obtain the target value.

Another approach for MODIS LAI data was proposed by Gao *et al.* (2008). The algorithm uses an augmented version of the TimeSat software for interpolation and asymmetric Gaussian function fitting. In the case of too many gaps or low quality data, TimeSat fails to fit a curve to the time series, therefore a gap-filling strategy was applied. The gap-filling process uses two major steps: first it searches an appropriate seasonal-variation curve for the gap and second, it adjusts the seasonal-variation curve to the sparsely available high-quality observation of the gap. Two strategies were used to search for an appropriate seasonal-variation curve. First, the algorithm searches for pixels with the same land cover type within a small window around the pixel. The algorithm checks if there are any successful TimeSat temporal curves and the pixel with the highest quality is chosen. Secondly, if a seasonal variation curve can not be located within the maximum search window, the algorithm averages all-high-quality seasonal-variation curves for each land cover type within a tile, referred as 'ancillary seasonal curve'. Once the ancillary seasonal curve is found, a regression transform function is computed such that the temporal-variation curve of the gap pixel can be computed.
Nightingale *et al.* 2009 (2009) applied the method to MOD 15 FAPAR products. They found that temporally and spatially gap-filled and smoothed MODIS FAPAR product removes noise present within the original MOD 15 FAPAR data set, while this technique might also smooth over some of the valid variations in the data. Large differences tend to occur during winter periods as a result of how the algorithm handles pixel's snow-contamination.

Both methods described above, use information from neighboring pixels to reduce temporal gaps in the time series. Here, we use the spatial resolution of models (REMO grid 18 km) as basis for the aggregation of SCA and NDVI time-series for different land cover classes or plant functional types.
The following steps are required for aggregation of time-series to the modelling grid: (i) geometric transformation into geometric projection of modelling grid (or *vice versa*) and (ii) aggregation of values to cells of modelling grid for relevant land cover classes (for example coniferous forest, wetland areas, agricultural areas, broadleaved forest).

The proposed processing scheme is outlined in Figure 6.

[1] MODIS Vegetation Continous Field product contains the percentage of trees, bar and herbaceous which add up to represent 100% ground cover (Hansen, 2003).

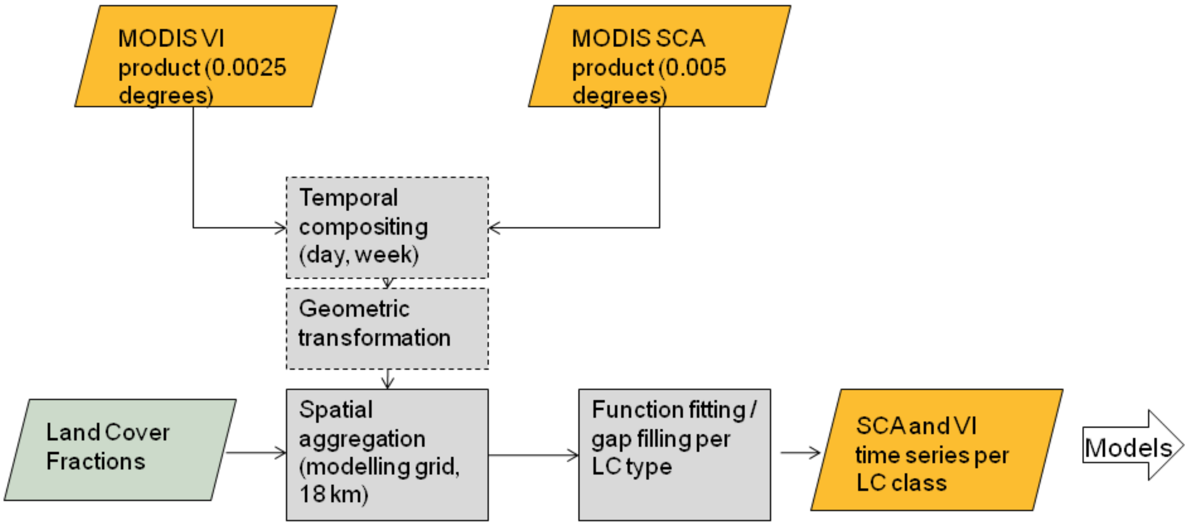

Figure 6. Scheme for processing of SCA and NDVI time-series to spatial resolution of modelling grid.

First, daily or weekly composites are calculated for MODIS vegetation index (VI) and SCA products. Afterwards geometric transformation to the modelling grid is performed (this step may be discarded when model output is transformed to regular latitude/longitude grid WGS-84). Aggregation of values is done for each land cover class seperatly, using the mean of all pixels with more than 90 % coverage of the specific land cover class. Outliers are removed using as criterion two standard deviations from the mean value. In the next step, gaps in the time-series are filled, using for example sigmoid function for SCA.
The resulting VI and SCA time-series can be used for the determination of carbon-balance related features, such as start of growing season and as basis for model validation.
The Figures 7 - 9 show examples of processed SCA time-series for year 2006 in Finland. Maps of fractional snow cover for 1/04/2006 and 1/05/2006 and corresponding information on number of days without observation are given in Figure 7 and Figure 8.
Temporal profiles of SCA are depicted for two locations in Figure 9.

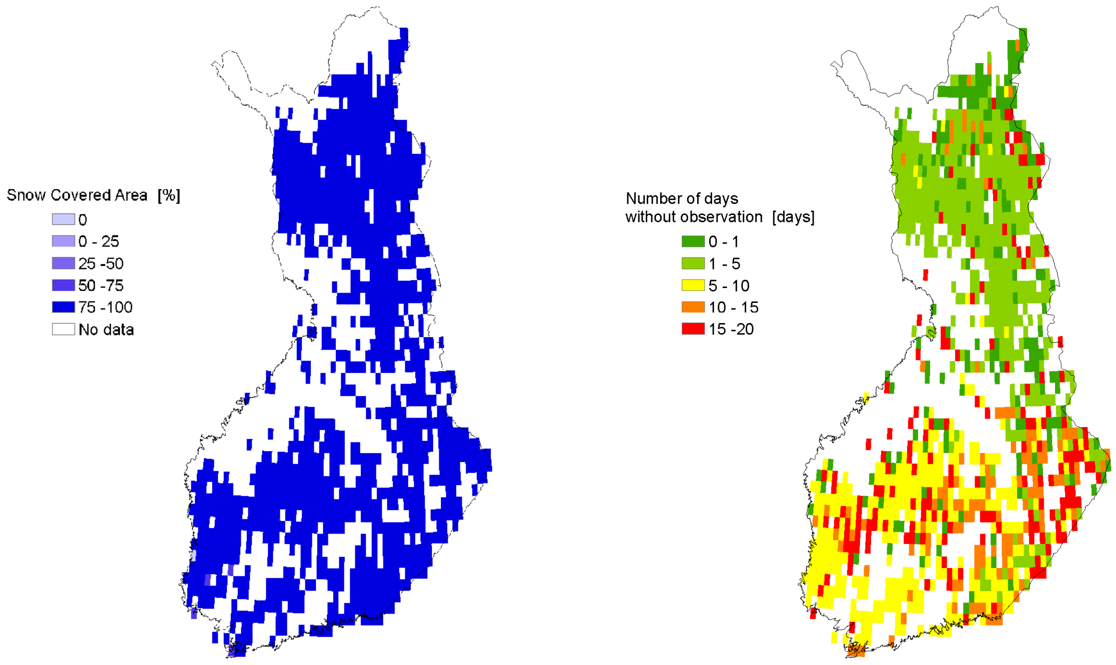

Figure 7. Snow Covered Area [%] in coniferous forest on 01/April/2006 (left) and number of days without observation on 01/April/ 2006 (right).

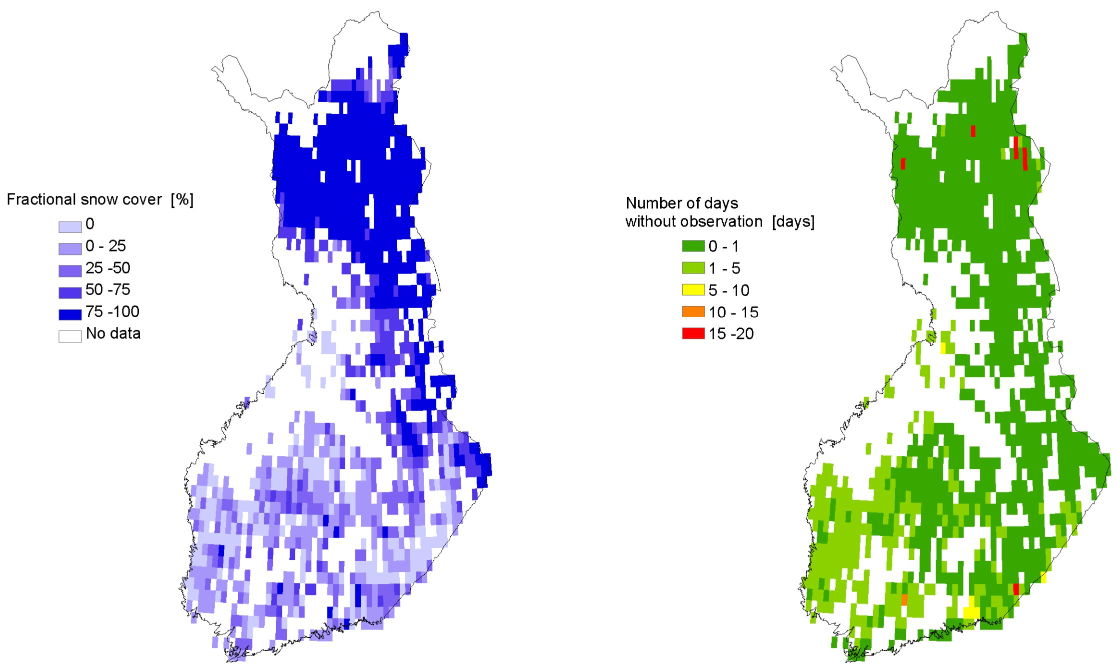

Figure 8. Snow Covered Area [%] in coniferous forest on 01/May/2006 (left) and number of days without observation on 01/May/2006 (right).

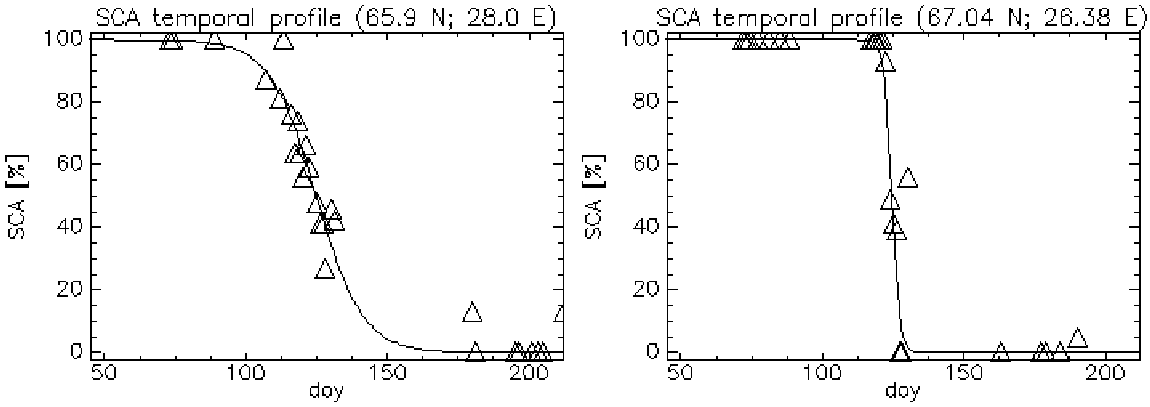

Figure 9. Temporal profiles of SCA [%] from coniferous forest at two locations in Finland. Gap-filled profiles based on sigmoid function fitting are shown with black line and observations are shown with black triangles. Values are aggregated for grid cell (0.17 x 0.17 degrees).

Processing results and the additional use of the multi-year temporal information in the processing chain, such as proposed by Fang *et al.* (2008) will be evaluated further.

Conclusions

This report describes further development for the filtering and interpolation of time-series reported earlier in deliverable of action 7 "Progress report on filtered time-series (2001 - 2008)". Specifically, quality information was added to daily gap-filled SCA time-series and smoothing of NDVI time-series from coniferous forest, necessary for the estimation of the start of growing season, was improved.

Furthermore, first steps are described for the processing of spatially and temporally continuous time-series of SCA and NDVI to be used for comparisons with models (action 6).

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