LIFE Project Number

LIFE12 ENV/FIN/000409

3rd report on the monitoring

Covering the project activities from 02/09/2013 to 31/03/2017

Reporting Date

31/03/2017

LIFE+ PROJECT NAME or Acronym

Climate change indicators and vulnerability of boreal zone applying innovative observation and modelling techniques

Project Data

Project location	Helsinki
Project start date:	02/09/2013
Project end date:	01/09/2017 **Extension date:** <dd/mm/yyyy >
Total Project duration (in months)	48 months (including **Extension of** <XX> **months)**
Total budget	2755288 €
Total eligible budget	2755288€
EU contribution:	1366952 €
(%) of total costs	49.61
(%) of eligible costs	49.61

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MONIMET Action C1

The impact of MONIMET project is monitored with a specific action (C1). The idea was to monitor the impact in the beginning of the project, during the project and at the end of project to see whether there is true communication between the different modeling and experimental approaches and thus convergence of the results at project end. There we defined indicators of the project impact that are common to the different approaches, and thus easily comparable. One such indicator is vegetation active period (VAP), which can be derived from webcam, flux tower, model and remote sensing results. Another indicator is albedo, which can be derived from flux tower, model and remote sensing results. Both VAP and albedo potentially obtain different values depending on the method of estimation, but for example experimental results can be used to tune model parameters, drawing the estimates closer together. In this report we present the methodologies and collect results of VAP and albedo estimation.

Start of growing season

VAP is the period between the end (GSED) and start day (GSSD) of the growing season. The GSSD is more easily deducible, because in boreal region the springtime development is rapid. Plenty of sunlight is available from early spring, and the clear change from freezing to above zero temperatures driven by synoptic weather patterns initiate the forest carbon exchange. Autumn is more challenging; while the irradiation conditions already start to inhibit photosynthetic uptake, the temperature usually stays at a level where forest could still be active. Furthermore, the dormancy development may initiate before the environmental conditions start to limit carbon exchange. Thus the development towards end of growing season is often gradual and it is difficult to determine a certain ending day. Furthermore, low sun elevation and frequent cloud cover make detection of the GSED difficult from satellite retrievals.

GSSD has been studied by Böttcher et al (2014) using Fractional Snow Cover (FSC), NDVI and NDWI time series from MODIS satellite, phenological observations (Äkäslompolo, Parkano, Paljakka and Saariselkä) and micrometeorological flux measurements (Hyytiälä, Kenttärova and Sodankylä). Micrometeorological flux measurements and phenological observations were considered as ground truth against which satellite measurements were compared. The GSSD from flux measurements was defined as the day on which the CO_2 uptake exceeds permanently the 15% level of the growing season maximum. The GSSD was obtained from the annual cycle of gross photosynthesis index, which indicates the apparent photosynthetical activity on a daily scale and is related to gross primary production (GPP). It is calculated as a difference of the daily averages of daytime (Photosynthetic Photon Flux Density (PPFD) > 600 µmol m−2 s−1) Net Ecosystem Exchange of CO_2 (NEE) and night-time (PPFD < 20 µmol m−2 s−1) respiration and is scaled with the growing season maximum. The growing season maximum is the 90^{th} percentile of the daily gross photosynthesis indexes during the month of highest uptake for the multi-year measurement period.

MODIS-derived FSC and vegetation indices (NDVI) were investigated for the use as proxy indicators for GSSD. Daily Terra/MODIS Level-1B data (1 km, 500 m and 250 m products) were collected for the period from February to October 2001–2010. FSC, varying from 0 to 1, was derived at a pixel size of 0.005 × 0.005° using the SCAmod algorithm. The method uses at-satellite observed single-band reflectance and pixel-wise average forest transmissivity for the provision of FSC.

Vegetation index (NDVI and NDWI) and FSC observations were averaged for all pixels of the seven above mentioned phenology and flux measurement sites. Gaps in daily observations due to cloud cover were filled using linear interpolation and smoothing schemes. GSSD was extracted from NDVI at the time when NDVI's spring-rise began. The general shape of snow depletion curves (changes of FSC during the melt season) for an area can be described by an exponential function, where two parameters are fitted for the melting period. GSSD was derived from the fitted function applying a constant threshold value for FSC.

The satellite indicators detected on average the growing season start 1–2 days later than in situ observations. Correlations between GSSD_NDVI and in situ dates were significant only for site Hyytiälä, whereas significant site-wise correlations between GSSD_FSC and in situ dates were obtained for sites Sodankylä and Hyytiälä, as well as a higher R2 for site Kenttärova. The range of GSSD from the southern to northern sites was captured with the indicators GSSD_NDVI and GSSD_FSC, but data points were grouped for the northern and southern sites, especially for GSSD_NDVI, implying that inter-annual differences at a specific site are less well captured by GSSD_NDVI.

Phenological observations on pine trees at four sites: Parkano, Paljakka, Äkäslompolo and Saariselkä for the years 2001–2010 were obtained from the Finnish Forest Research Institute (METLA). Phenological observations were carried out twice a week in advanced thinning stands. Beginning of shoot elongation can be referred to as growth of pine start date (GPSD). GPSD is usually later than GSSD. MODIS-derived vegetation indices (NDWI) were investigated for the use as proxy indicators for GPSD. GPSD is related to the end of snow melt as described by the decrease of NDWI. Satellite derived GPSD_NDWI accounted only for 54% of the variation in situ observations and data points were dispersed and grouped by site. Site-wise correlations were not significant; hence inter-annual variability at site-level cannot be captured. Mean GPSD for each phenological site could nevertheless be depicted by NDWI timeseries with bias ranging from −2 to 3 days for different sites.

Modeling (JSBACH, the land surface component of MPI-ESM) results have also been compared to remote sensing results ((Böttcher et al. 2016a). GSSD was extracted from the model annual cycle of gross photosynthesis index similarly to flux observations. The site level correlations were significant for Hyytiälä, but not for Sodankylä. The regional level comparison with satellite results showed that with the multi-year averages the general dynamics of GSSD was rather well captured by JSBACH. However, consistent biases of two to four days were found for GSSD of evergreen conifers when the results were averaged over northern, middle and southern Finland, indicating that the model predicted earlier growing season start than the satellite observation. Biases of three to seven days were found for the deciduous broadleaved forests, indicating later growing season start by the model.

In the deciduous broadleaved case, the simulations of the start of season were slightly improved by adjusting JSBACH phenology parameters, but the model formulation seems not optimal regarding the south–north gradient in Finland. For the correct prediction of the start of the vegetation active season in coniferous forest, the JSBACH photosynthesis model is more important than the phenological model. Hence, JSBACH photosynthesis parameters would need to be modified to limit too strong photosynthesis in early spring and to improve the simulated gross primary production. The seasonal dynamics of photosynthesis can be related to seasonal variations in ambient temperature. Kolari et al. (2007) derived a sigmoidal relationship between photosynthetic efficiency and temperature history using in situ observations of pine shoot gas exchange in Värriö and Hyytiälä sites. This result was used in JSBACH model to tune the photosynthetic potential carboxylation rate (Vcmax), in order to make the model respond better to variations in springtime temperatures. The calibrated parametrisations were successfully used in VAP calculations (See Fig. 3 below). Further work, as presented in MONIMET Action B4 Second progress report, is ongoing to yield better agreement between the different approaches.

According to PRELES model, the start day of growing season agrees well with the start day retrieved from the micrometeorological flux observations at Hyytiälä and Sodankylä (Fig. 1). Hyytiälä data is from years 2000 – 2010 and Sodankylä data from 2001 – 2009.

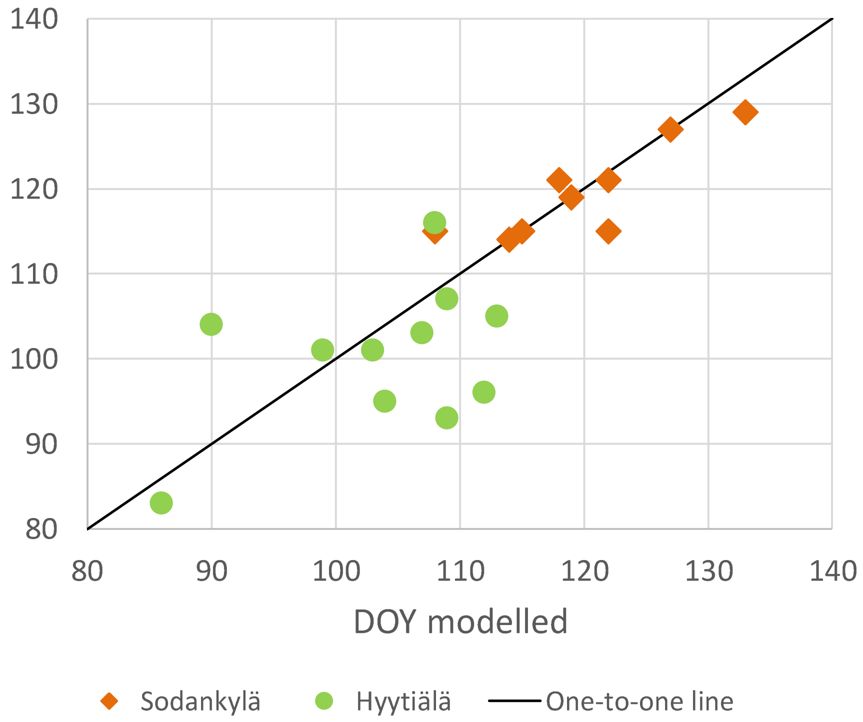

Fig. 1. Start day of the growing season (GSSD) according to PRELES model and observed start day according to Sodankylä and Hyytiälä micrometeorological flux measurements.

End of growing season

Though more challenging than the start of growing season, procedures have already been developed by the project team for extracting the end of growing season from MODIS satellite NDVI time series and micrometeorological flux measurements (Böttcher et al., 2011). Site comparisons have been made for Hyytiälä, Sodankylä and Kenttärova. Also the phenophase end of height growth of Scots pine (Pinus sylvestris) in Parkano and of Norway spruce (Picea abies) in Pallasjärvi for years 2001-2010 were utilized.

From flux measurements the following criteria were used for determining the end of season: when daytime Net Ecosystem Exchange (NEE) in autumn first decreases below 20% of the maximum summer uptake (most negative NEE); and when Gross Primary Production (GPP) falls permanently below a certain threshold level of the growing season maximum: 50%, 40%, 30%, 15%, 10% and 5%. The growing season maximum was defined as the 98^{th} percentile of GPP values during the month of highest uptake for a multi-year period.

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

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. The other GPP based phenological indicators 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. Large variations of scaled NDVI for indicators 50% GPP and 40% GPP hindered the application of the threshold for the determination of these events from NDVI time-series.
The day when NDVI had its maximum in summer was compared to phenological observation of end of shoot elongation. The correlation between the two indicators was 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 measure for the end of growing season from NDVI time series revealed low correlations with phenological indicators describing different levels of GPP decrease in autumn at CO_2 flux measurements sites. 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. Furthermore, simple NDVI threshold values seem not to be applicable for extraction of the end of growing season for evergreen coniferous sites.

Further comparisons were made between the GPP-based end of season indicators (15%, 10% and 5% Gross Photosynthesis, GP) and the start of snow accumulation and soil freeze in autumn (Böttcher *et al.*2016b). While we found good correlation between the end of the season indicator

GP 10% and the start of snow accumulation from in situ observations of snow depth at weather stations (R^2=0.69, Fig. 2a), the correlation with a similar start of snow accumulation indicator from weekly GlobSnow SWE time series was low (R^2=0.44, Fig.2b). In addition, there was a delay of 20 days of the GlobSnow SWE derived indicator to the *in situ* date.

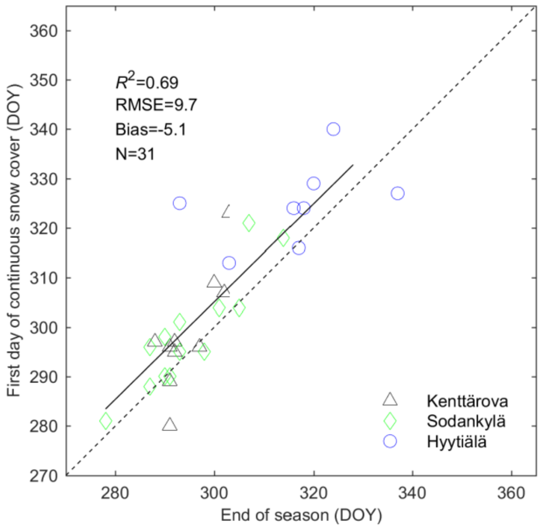

Fig2a. Scatterplot of the end of the vegetation active period (PI threshold 10%) versus the first day of continuous snow cover from *in situ* snow depth measurements DOY is the day of year.

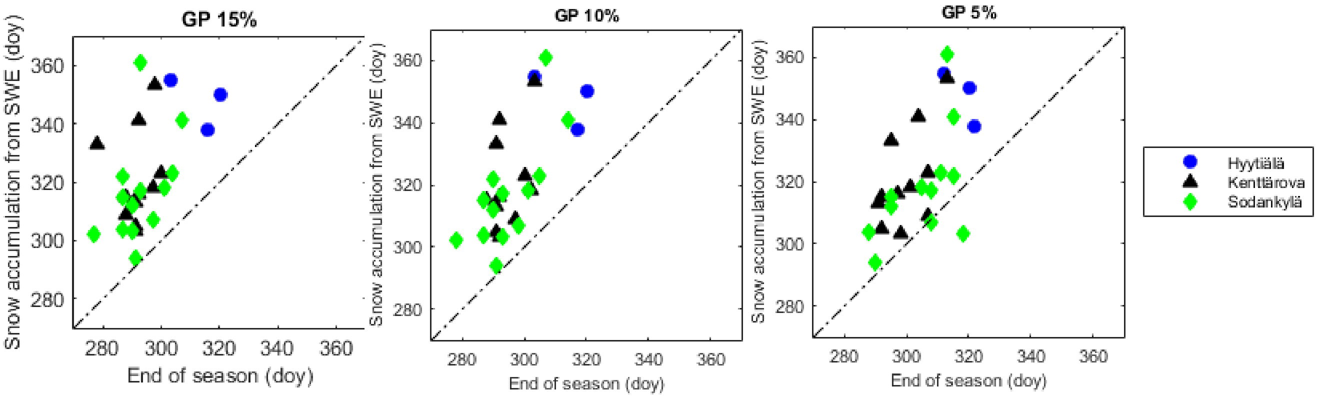

Fig 2b. Scatterplots of the end of season estimates from CO_2 flux measurements versus the start of the snow accumulation period from the weekly GlobSnow SWE.

The end of season indicators (GP 5% and GP 10%) showed significant correlations with the date of partially frozen soil from satellite observations for sites Sodankylä and Kenttärova in northern Finland (R^2>0.6, GP 10%). Partially frozen soil was in average observed 3 days after and 4 days days before the end of season based on the GP 5% and 10% thresholds, respectively. Because the soil freeze data from satellite observations is only available from 2010 onwards, the number of comparison pairs is low, especially for Hyytiälä, and further investigations with additional data are needed. The end of season can be retrieved from the model results using GPP similarly to the procedure described above for the flux measurements.

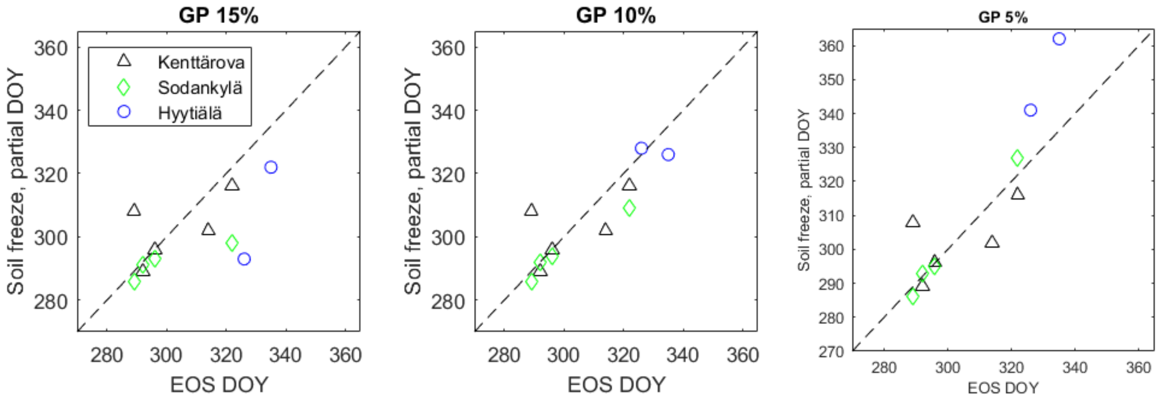

Fig 2c. Scatterplots of end of season estimates from CO_2 flux measurements versus the date when the soil is partially frozen as observed from Soil Moisture Ocean Salinity instrument.

Vegetation active period

The beginning of the season, end of season, and their difference (VAP) has been calculated using the different tools and methods described above. Webcam results have been added to the portfolio. VAP from model results is shown below (Fig. 3a), using a threshold of 15% GPP for both start of season and end of season. The result is averaged over the period from year 1980 to year 2011, and it clearly shows the south-north gradient in VAP. Difference to VAP results using calibrated JSBACH model is also shown (average between years 2001 - 2011). There the relationship between photosynthetic efficiency and temperature history has been taken into use in the model, delaying the springtime start of vegetation active period due to cold spells. VAP from calibrated PRELES model is shown in Fig. 3b. The south-north gradient is clearly visible there, and the results are generally in agreement with JSBACH.

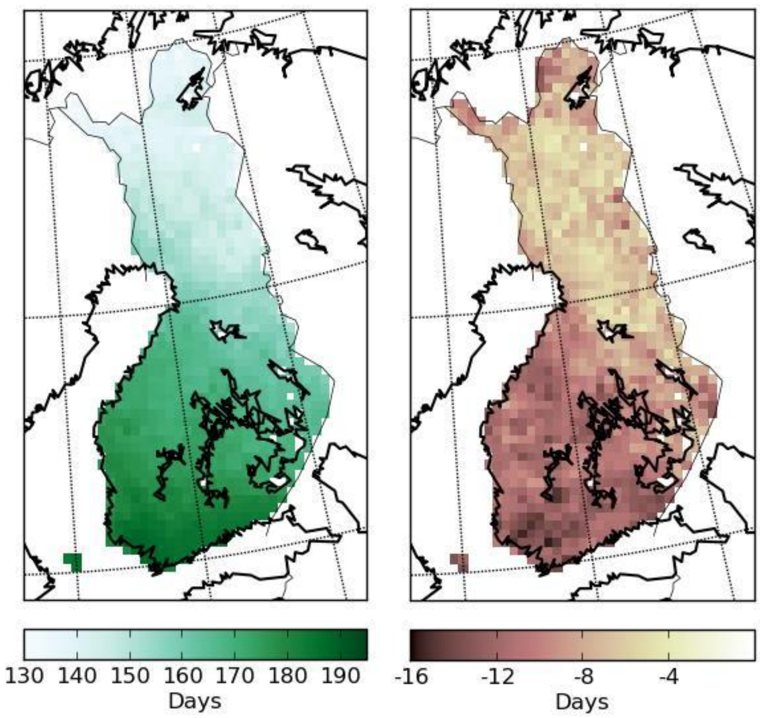

Fig. 3a. Left: Vegetation active period according to JSBACH model results, right: Difference to calibrated JSBACH model results.

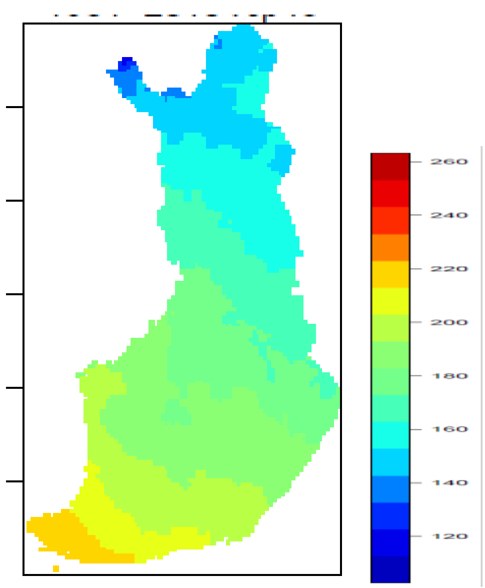

Fig. 3b. Vegetation active period according to PRELES model results, average between 1981 – 2010.

Webcam results for GSSD and GSED are shown in Fig. 3c together with JSBACH model results. JSBACH results cover the period 1981-2017, and GSSD and GSED averages over these years are shown for several webcam and phenology monitoring sites. JSBACH results show the latitudinal gradient, against which the webcam results from year 2014-2016 are compared. The gradients are quite similar, however the definition of the end of growing season in the model needs further consideration, which can better assessed when there are more webcam years available.

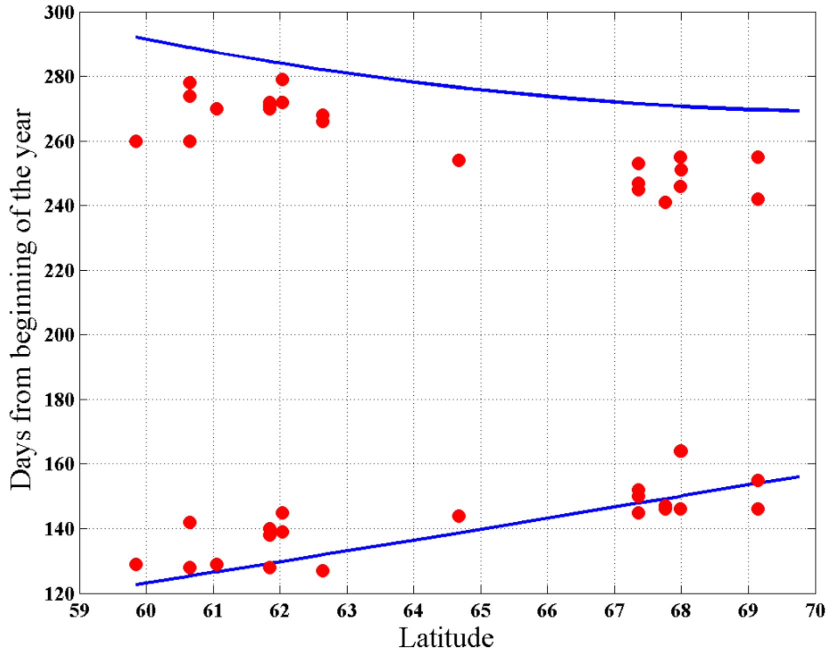

Fig. 3c. Webcam results for GSSD and GSED and JSBACH average GSSD and GSED results for a set of observation sites in Finland. JSBACH is shown in blue and Webcam in red.

Albedo

The total surface albedo can be retrieved from remote sensing as well as models and in situ measurements. The alteration of snow covered and snow free periods create a distinct annual cycle in albedo in boreal region. During the growing season some albedo variation is created through changes in vegetation cover and leaf status. Rinne et al (2007) successfully used NOAA/AVHRR satellite measurements of surface albedo for detecting snow disappearance, which can in turn be connected to start of growing season, as discussed above. Autumn is again more difficult for albedo retrievals, hence the satellite based analysis was restricted to sprint and summer. Here a long albedo time series (AVHRR CLARA-SAL) were applied, and compared to model albedo development.

Data from the new release of the CLARA-SAL product is shown in Figure 4 together with JSBACH total surface albedo results. The data is averaged over the period from 1982 to 2015, and is shown for the different, mainly boreal, vegetation zones in Finland. In addition to climate drivers, albedo is affected by e.g. the leaf area index and plant species, and contribution from bare ground. CLARA-SAL albedo shows larger variation and decreases to lower summer level than JSBACH albedo. The CLARA-SAL values contain contributions from surface water in mixed pixels, which decreases the summertime albedo values. The spring decrease also occurs later than in JSBACH, indicating later snow melt. The seasonal cycle of model albedo is largely driven by the climate drivers and existence of snow cover, and thus a significant impact on model results could be achieved through applying alternate snow descriptions. This is left for future work.

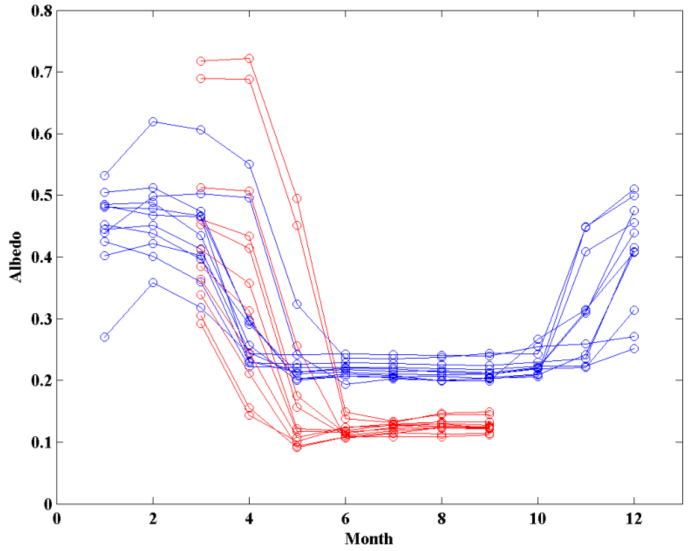

Figure 4. Annual cycle of albedo in the different vegetation zones in Finland. CLARA-SAL is given in red and JSBACH results in blue. Full year is not shown for CLARA-SAL because lack of sunlight prohibits albedo estimates during winter.

The melting season start date (MSSD) was estimated from the albedo results using the same methods than above for GSSD from the the NDVI, NDWI and FSC data. The springtime start of rapid albedo decrease, was interpreted as start of snow melt (MSSD), and end of decrease as end of snow melt (MSED). Figure 5 shows the MSSD dates from CLARA-SAL product. The results are in qualitative agreement with earlier GSSD results.

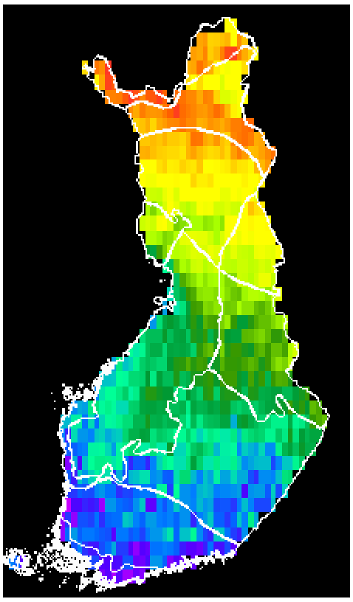

Figure 5. The start of the melting season (MSSD) from CLARA-SAL albedo. The purple colour refers to MSSD of 60 and red colour to MSSD of 120. Data from period 1982-2015 was used.

The MSSD and MSED from CLARA-SAL albedo for areas of Lepsämänjoki and Mustajoki are presented in Fig. 6 for years 1982-2015. Year-to-year variation is quite large. MSED shows less variation than MSSD. The data from years 2014 and 2015 could not be reliably interpreted.

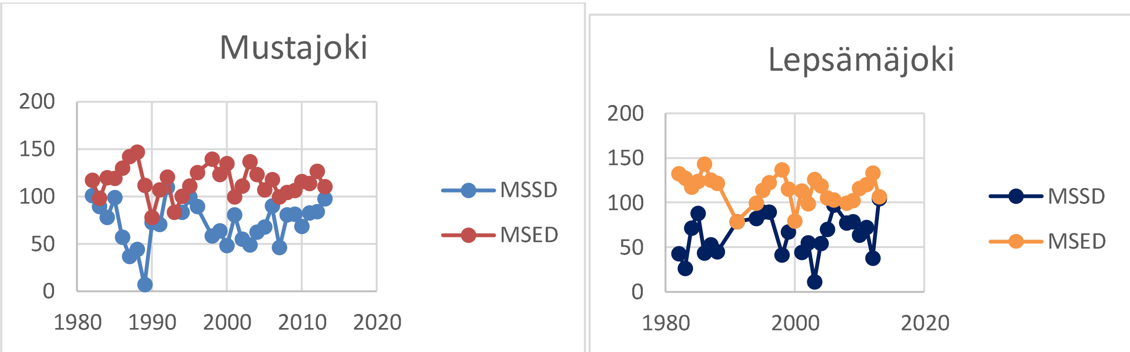

Figure 6. MSSD from CLARA-SAL albedo for Lepsämänjoki and Mustajoki.

Conclusions

The start, end and length of the vegetation active period (VAP) were estimated from flux measurements, satellite observations, and by two models, JSBACH and PRELES. Albedo estimations were obtained from satellite (AVHRR CLARA-SAL) time series and JSBACH model. The albedo results showed a distinct annual cycle with largest changes occurring in the time of snow melt and onset of snow cover, The results for vegetation active period showed that the definition of VAP can be challenging, but results that are comparable within the different approaches can be obtained, and that models can be trained with experimental data regarding VAP.

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