Time courses of reflectance for some forest types in Estonia

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Abstract. Seasonal and daily reflectance courses for a few types of forest from the Järvselja area, Estonia were studied. 'Climatological' seasonal courses were determined for six Landsat bands using 47 Landsat and SPOT images from an extended period of years. For better comparability, the growing degree day time axis was used to plot the image data from different years. Most pronounced seasonal changes were found for deciduous birch dominated forests in spectral bands corresponding to strong absorption by chlorophyll (TM3) and water (TM7) and in the near infrared band (TM4) sensitive to the total amount of leaf tissue. Considerable seasonal reflectance changes appeared to be in sparse pine bogs due to the dependence of reflectance on Sun elevation. Due to applied smoothing of the image calibration coefficients, climatological series can be applied even for individual stands or plots of size >1ha. Images from different satellite sensors were used to create seasonal reflectance series of three sample plots of 100x100m. The agreement between different sensors was satisfactory. A comparison with the helicopter-borne spectrometer measurements over the same targets showed that the atmospheric correction of the satellite images tends to somewhat overestimate surface (forest) reflectance. A partial thinning made in the birch forest was seen during the next summer after thinning by decreasing the reflectance in the near infrared band and increasing in the red band. The climatological seasonal reflectance series can further be used to simulate climatological estimates of forest productivity and carbon balance.

Keywords. Multispectral reflectance, Landsat TM, SPOT, seasonal course, hemiboreal forest.

1. Introduction

While monitoring the state and productivity of forests via remote sensing all aspects of temporal changes in forest reflectance - successional, seasonal and daily courses have to be considered. Seasonal course of forest reflectance in different spectral bands is important in several aspects, primarily in relation to monitoring forest phenology. A majority of the forest productivity and carbon balance models that rely on the Monteith relation to predict the yearly net or gross primary production make use of the seasonal course of multispectral indices derived from the reflectance in specific spectral bands to represent the fraction of absorbed photosynthetically active radiation (PAR). Moreover, the "climatological" average seasonal course of reflectance together with typical successional and daily courses can serve as a basis for building a remote sensing based forest monitoring system.

To study stand-level estimates of forest productivity and carbon balance the current MODIS net primary productivity (NPP) product is too coarse. Thus, higher spatial resolution data are needed. Due to the relatively low revisit capability of most popular medium resolution scanners (Landsat TM and ETM+, SPOT) and frequent occurrence of clouds, the reconstruction of reliable seasonal courses of reflectance in different spectral bands in boreal and temperate regions is difficult during a single growing season. We have to be able to include images from multiple spaceborne and airborne sensors acquired at different moments of the successional stage, season and day. One of the alternatives is to create “climatological” mean successional, seasonal and daily curves of reflectance for several forest types in key spectral bands and for multispectral indices. It is possible to accumulate cloudless images over several years to cover the whole vegetation period. A natural way to produce the time series is to calibrate the images into the units of top-of-canopy (TOC) reflectance factors by making use of the absolute calibration and atmospheric correction of images. In spite of apparent success in the atmospheric correction procedures, the resulting time series is typically scattered and may need some additional smoothing. When images from multiple years are used, a problem of phenology differences between the years arises. To account for the interannual differences in meteorological conditions, a concept of accumulated or growing degree-days (GDD) or temperature time has often been used.

The main aim of the present paper is to derive the climatological seasonal reflectance courses for a few forest types and to show the applicability of the associated smoothing method to study the seasonal reflectance courses for individual stands up to 1 ha in size. In addition, to point out the usefulness of radiative transfer models to better interpret the empirical reflectance data.

2. Methods

The study area is located in Järvselja Training and Experimental Forestry District (Estonia, 58.15°N, 27.28°E), a representative of the lush hemiboreal zone forest. The dominating tree species are Silver birch, Scots pine, and Norway spruce. The site types vary over a large range from fertile types to infertile transitional and raised bogs and lowland mires [1].

2.1. ‘Climatological’ seasonal reflectance series:

Altogether there are 47 Landsat TM, ETM+ or SPOT images covering the whole (snow free) vegetation period from the period of time from 1986 to 2009. Six spectral bands corresponding to Landsat TM bands were used and the equivalent SPOT bands were treated as the same bands. The images were arranged into a seasonal series according to the Growing Degree Days (GDD) as the time axis. All reflectance values were reduced to the (hemispheric-directional) TOC reflectance factor units. A method of smoothing the calibration coefficients suggested in [1] was used. The method assumes that the ‘climatological’ average seasonal reflectance curves during the snow free period of the year should be smooth. A smoothing procedure was used to correct the two calibration coefficients defining the linear relation between TOC reflectance and the digital number (DN) representation for each image in each spectral band. The corrected calibration coefficients were selected so that the squared sum of residuals between the smoothed seasonal curve and initial TOC reflectance values for a selected sample set of stands was minimized. Next, the corrected calibration constants were applied to the time series of images for all the study stands.

Table 1. Description of the four forest types queried from the Järvselja database to study the climatological seasonal course of reflectance. All queried stands are >1.5 ha in size and >70% of main tree species.

Selection name	**Dominating tree species**	**Orlov (1929) site index**	**Stand age (yrs)**	**Site fertility, Avg H100 (m)**	**No of stands in the query**	**Total area (ha) in the query**
Fertile Pine	*Pinus sylvestris*	<3	≥50	Fertile, 27.0	10	25.4
Spruce	*Picea abies*	<3	≥40	Fertile, 29.0	30	48.5
Fertile Birch	*Betula pendula*	<3	≥40	Fertile, 28.2	58	138.5
Pine Bog	*Pinus sylvestris*	≥5	no	Infertile transitional bog	31	436.8

This way the climatological seasonal series of reflectance were derived in six spectral bands for a few forest types in Järvselja. In the present paper, four types of forest were queried from the Järvselja forest database and analysed for the seasonal course of reflectance: Fertile Birch, Spruce, Fertile Pine and Pine Bog selection. The same selections were used in the smoothing procedure of image calibration coefficients. A brief description of the forests is given in Table 1.

2.2. Seasonal reflectance course for individual plots from different satellite sensors:

Images from different available satellite sensors were used to study the seasonal development of reflectance for three 100x100m sample plots established for a detailed study. A brief description of the plots is given in Table 2.

Table 2. Characteristics of three study sites (100-m x 100-m) in the Järvselja area used to examine seasonal courses of reflectance. For more details on these stands see [2].

Stand name	Dominating tree species in upper layer	Tree species in lower layer	Stand age (yrs) in 2007	Site type and fertility, H100 (m)	Understory and soil layer	Other remarks
Pine	*Pinus sylvestris*	None	124	transitional bog infertile, 10.8	*Ledum palustre, Eriophorum vaginatum, Sphagnum* ssp.	
Spruce	*Picea abies*	*Betula pendula*	59	*Oxalis-Vaccinium myrtillus,* fertile, 28.1	mosses *(Hylocomium splendens, Pleurozium schreberi)*	High canopy cover (0.89), thus sparse understory
Birch	*Betula pendula*	*Tilia Cordata, Picea abies*	49	*Aegopodium* fertile, 28.7	several grass species	Thinned in 2004 fall

Images from the following sensors were used:

1. A multi-year Landsat /SPOT climatological seasonal series whose calibration coefficients have been smoothed according to the procedure described in 2.1.
2. CHRIS PROBA images of 10 July 2005, 5 July 2010, and 27 July 2011. View direction nearest to the nadir was used in this study.
3. A Hyperion image of 18 August 2005.
4. World View 2 (WV-2) image of 28 August 2011.

In addition, the results of low altitude helicopter-borne measurements by means of a UAVSpec3 (400-1050nm) spectrometer [3] were used for the comparison. Satellite images were atmospherically corrected by means of 6S algorithm using the atmospheric data from the NASA Aeronet sunphotometer located at Tõravere (ca 50km from the site). For the earlier images lacking the sunphotometer data, the dark target method was applied to estimate the aerosol optical thickness. No atmospheric correction was applied to the results of UAVSpec measurements.

2.3. Model simulations:

Simulations by the forest radiative transfer model FRT [4] were used to help to interpret the results of measurements. In particular, the reflectance dependence on solar angle was simulated to interpret the possible daily reflectance changes, since the present image sets do not allow to study daily changes

3. . Results and discussion

3.1. 'Climatological' seasonal reflectance curves:

The climatological seasonal series of reflectance in four Landsat TM bands are given in Fig. 1 for the four types of forest as described in Table 1.

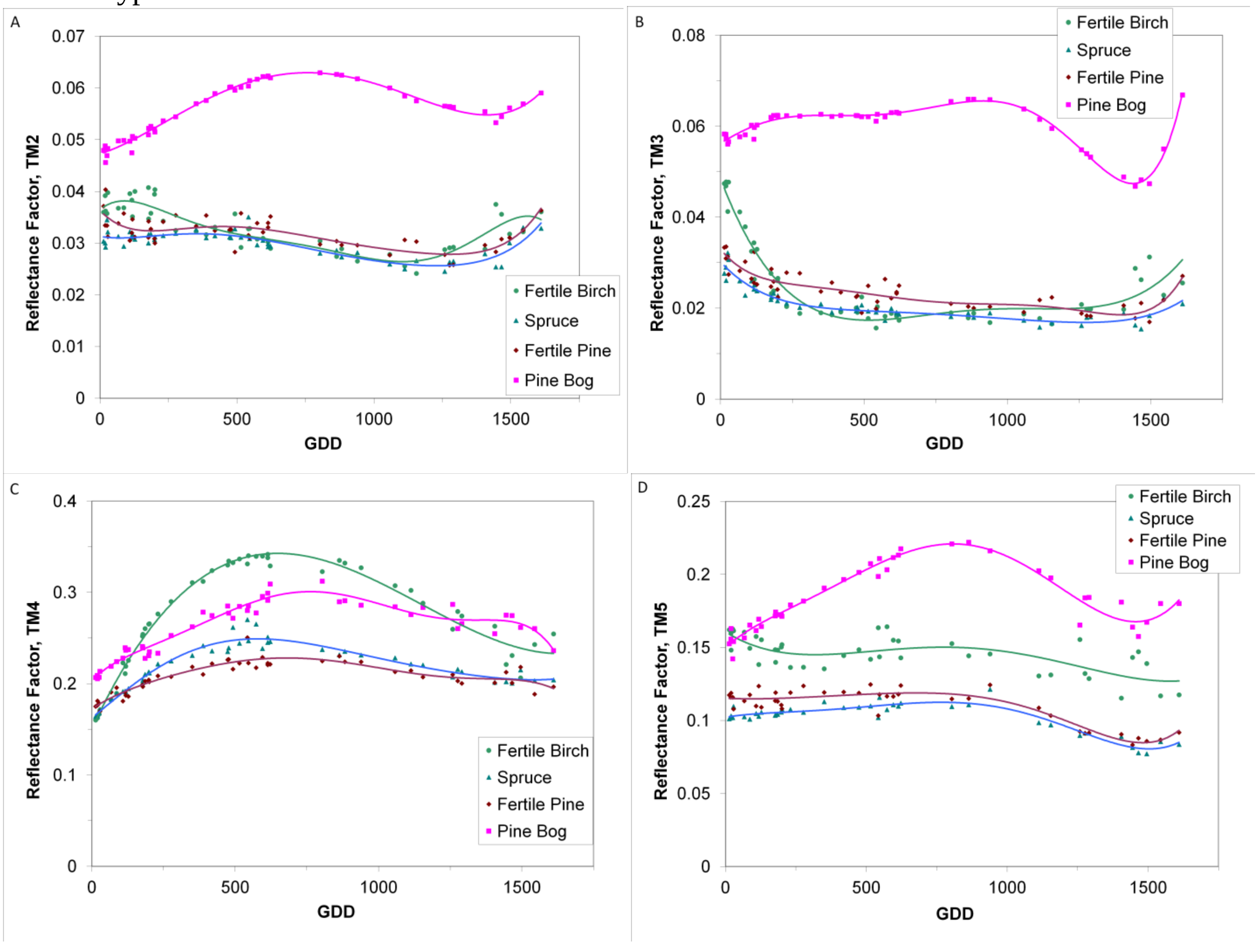

Figure 1: The climatological mean seasonal curve of reflectance for the Fertile Birch, Spruce, Fertile Pine and Pine Bog stand selections from Järvselja, Estonia plotted on the Growing Degree Days (GDD) time axis. Spectral bands shown: A – TM2 (520-600nm), B - TM3 (630-690), C – TM4 (780-900), D – TM5 (1550-1750).

Most seasonal changes in Fig. 1 are expected from theoretical considerations. In the visible bands and TM4 birch forests show a clear correlation with the total amount of chlorophyll per unit ground area and green LAI, respectively. Some problematic behaviour of the seasonal curves is seen during late autumn, probably due to larger reflectance variation owing to weaker signal, lower Sun and higher sensitivity to errors in atmospheric correction. A different seasonal course for the Pine Bog is seen in TM3 compared with TM1 and TM2, possibly caused by higher amount of red pigments present in the ground vegetation and less chlorophyll absorption. Somewhat different behaviour of reflectance in the middle infrared bands TM5 and TM7 (not shown) is unexpected. Forest fire people state that up to 30% decrease in needle water content is observed in the period of growing new leaves by the end of May/early June in North America [5]. Both these bands are also sensitive to the contents of organic compounds (lignin, cellulose, protein) in leaves, however, absorption by water still dominates. Old needles may be drier during that period, but it is not clear whether the total amount of water per unit ground area should decrease, since new needles appear. When the same average climatological reflectance curves are plotted on the day-of-year axis for e.g. ten year period, the seasonal curves show a lot of variation due to the different course of air temperature in the particular growing season. For Fertile Birch selection, it is interesting to point out that in some autumns we cannot see the considerable reflectance increase in the red band, since the GDD values have not reached the values when on average the massive leaf yellowing typically takes place.

3.2. Daily reflectance course:

Simulations by the FRT model [4] showed us that for the closed-canopy forests the dependence of nadir reflectance on solar zenith angle is not very pronounced while larger dependence is expected for the sparse forests such as the pine bog. For instance, in the red band the change in solar zenith angle from 30 to 60º caused the relative nadir reflectance decrease by ca 23% for Pine Bog, 9.3% for Fertile Pine, 3.7% for Spruce and -3.4% for Fertile Birch selection. In the NIR band, the respective changes were considerably less, 8.2%, 4.7%, -1.1% and -4.0%, respectively. These results enable us to explain why the seasonal reflectance change was the largest for the Pine Bog selection (Fig. 1).

3.3. Seasonal reflectance course for 1ha sample plots:

For the 1ha plots seasonal reflectance curves were determined from multiple image sources including the climatological series. As examples, reflectance courses in the red (TM3) and NIR (TM4) bands are presented for the Birch plot in Fig. 2 and for the Spruce and Pine plots in Fig. 3. The standard deviation of reflectance is determined by the pixel size. After the thinning in fall 2004 the most remarkable reflectance changes ocurred in the next summer (2005) in TM3 and TM4 bands, however, starting from 2006, the reflectance values cannot be reliably discriminated from the average curve before thinning. Reflectance factors determined from the UAVSpec measurements tend to be lower than the values determined from the satellite images and atmospheric correction. It seems that the applied atmospheric correction tends to somewhat underestimate atmospheric contribution in the top-of-atmosphere signal.

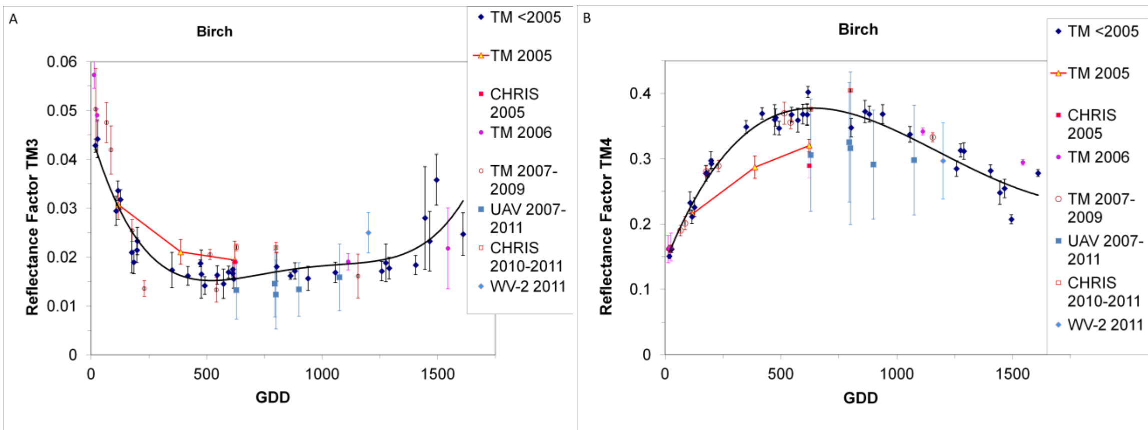

Figure 2: Seasonal reflectance course of the 1ha Birch plot as determined by multiple image sources. A – red band TM3, B – NIR band TM4. The error bars show the standard deviation of reflectance. The stand has been thinned in fall 2004.

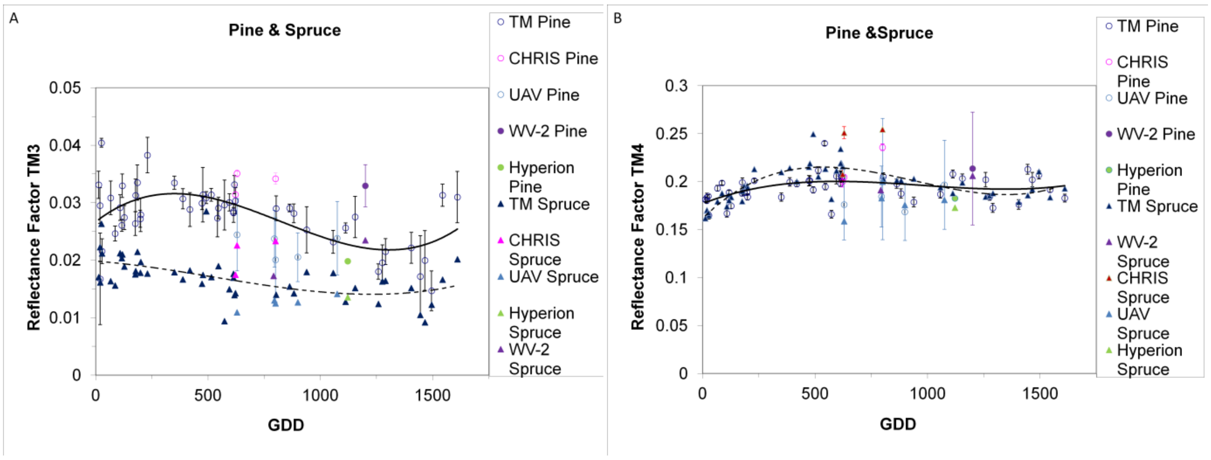

Figure 3: Seasonal reflectance course of the Pine and Spruce 1ha plots from multiple sources. A – red band TM3, B – NIR band TM4. The Pine points are supplied with the standard deviation error bars.

The seasonal courses of reflectance for the Pine and Spruce plots are rather similar to each other, however, the Pine plot is systematically brighter in all studied bands, except for the NIR band.

4. Conclusions

The method of creating climatological seasonal reflectance series is suitable for extended selections of similar forest types (>20ha) within the areal limits of image series as well as for individual forest stands of sufficient size (1ha). The method is convenient to apply if forestry databases over the region of interest exist. Multiple sources of images can be used, however, the corrections for the BRDF and spectral effects between the sensors may be needed. Atmospheric correction of satellite images tends to slightly overestimate forest reflectance. The uncertainties caused by sensor calibration and atmospheric correction of the images are still of the order of magnitude that hinder the detection of some types of change (like partial thinning). We need ground-based and low-altitude reflectance measurements to compare with and, if needed, to recalibrate satellite images. The climatological seasonal series can further be used to simulate climatological estimates of forest productivity and carbon balance.

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References

[1] Nilson T, T Lükk, S Suviste, H Kadarik & A Eenmäe, 2007. *Calibration of time series of satellite images to study the seasonal course of forest reflectance*. Proc. of the Estonian Academy of Sciences, Biology/Ecology, 56, 5-18.

[2] Kuusk A, J Kuusk, & M Lang, 2009. *A dataset for the validation of reflectance models*. Remote Sensing of Environment, 113(5), 889-892.

[3] Kuusk J & A Kuusk, 2010. *Autonomous lightweight airborne spectrometers for ground reflectance measurements*. 2nd Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS 2010), Reykjavik, Iceland, June 2010. CD-ROM, 4pp.

[4] Kuusk A & T Nilson, 2000. *A directional multispectral forest reflectance model*, Remote Sensing of Environment, 72(2), 244-252.

[5] Alexander ME, 2010. *Foliar moisture content input in the Canadian Forest Fire Behavior Prediction Input System for areas outside Canada*. VI International Conference for Forest Fire Research. DX Viegas (Ed), 13pp.