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Remote sensing of spring phenology in boreal regions: A free of snow-effect method using NOAA-AVHRR and SPOT-VGT data (1982–2004)

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Abstract

Measurements of spring phenological dates in boreal regions using NDVI can be affected by snowmelt. This impacts the analysis of interannual variations in phenology and the estimates of annual carbon fluxes. For these two objectives, snowmelt effect must be removed from the phenological detection. We propose a methodology for determining the date of onset of greening in the 1982–2004 period using SPOT-VEGETATION (VGT) and NOAA Advanced Very High Resolution Radiometer (AVHRR) data. From 1998 onwards, the date of onset of greening is taken as the date at which the Normalized Difference Water Index (NDWI), calculated from SPOT-VGT near and short-wave infrared bands, starts increasing. This index decreases with snowmelt but increases with vegetation greening. For the 1982–2001 period, the date of onset of greening is the date at which AVHRR-NDVI equals a pixel specific threshold (PST), determined using the results of the NDWI method in the years common to the two datasets. The methods are validated using in situ measurements of the dates of leaf appearance. RMSE of 6.7 and 7.8 days, respectively, is found using NDWI-VGT and PST-NOAA methodologies, and the difference between the two methodologies in the common years is small. Very importantly, the dates are not biased. The interannual variations of the 23-year spring phenology dataset on the study area in northern Eurasia are analysed. In average over the study area, an advance of 8 days and a delay of 3.6 days are, respectively, found over the periods 1982–1991 and 1993–2004. These results confirm and complete previous studies about the greening trend, remove the uncertainty due to snow, and may improve carbon budget calculations.

Keywords: Phenology; Snow; Boreal; Siberia; SPOT-VEGETATION; NOAA-AVHRR; Leaf appearance; NDVI; NDWI; Spring

1. Introduction

Phenology of many organism types in terrestrial ecosystems has been clearly identified to be disturbed by climatic changes (Parmesan & Yohe, 2003; Root et al., 2003; Walther et al., 2002). In recent years, remote sensing satellite data have been used at regional and global geographic scales as an objective means to assess the interannual variations in the phenology of deciduous vegetation foliage, i.e. the timing of foliage appearance and senescence. In particular, the time series of the Normalised Difference Vegetation Index (NDVI) from the NOAA Advanced Very High Resolution Radiometer (AVHRR) has been used to demonstrate a trend of earlier greening in the northern latitudes since 1982 (Myneni et al., 1997, 1998; Slayback et al., 2003; Tucker et al., 2001; Zhou et al., 2001). The statement was based on the trend in the timing of the NDVI increase in spring. However, in boreal regions, where strong impacts of climatic change on vegetation phenology are expected, NDVI also increases during snowmelt (Moulin et al., 1997). Consequently, an earlier NDVI increase could be due either to an earlier vegetation onset or to an earlier snowmelt (Dye & Tucker, 2003; Shabanov et al., 2002). Since both snowmelt and greening events are driven by temperature, a trend in the dates of NDVI increase indicates a general warming or cooling effect, without giving any specific information on the related surface processes.

Recently, several approaches have been used to detect spring phenology in boreal regions, accounting for the presence of snow. Zhang et al. (2004) replace any record at which snow

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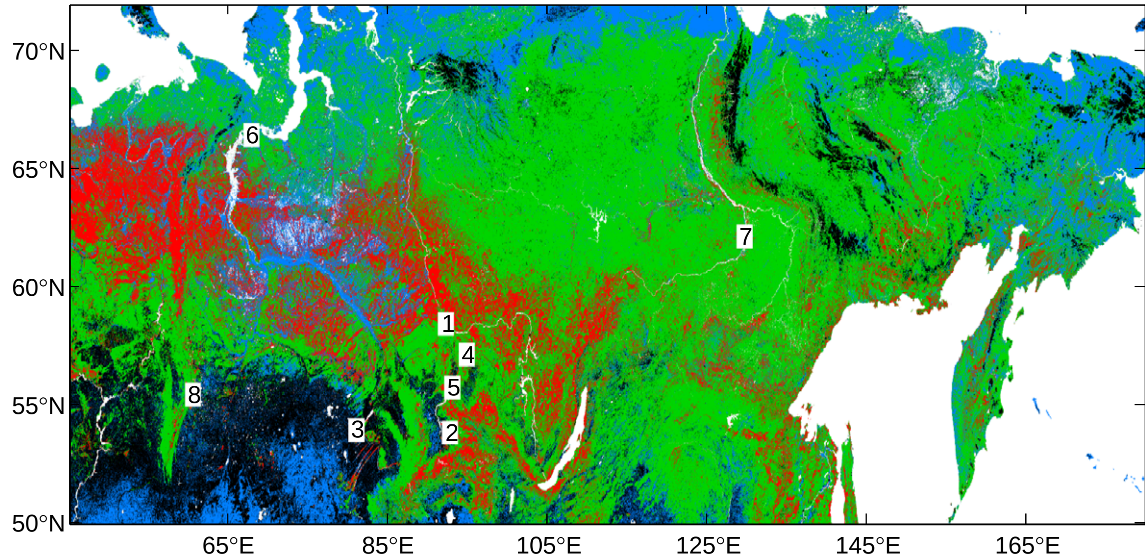

Fig. 1. Land cover map of the study area, extracted from the GLC2000 map (Bartholomé & Belward, 2005). The original cover classes are regrouped in five broad classes. In red is the evergreen vegetation (forests and shrubs), in green deciduous vegetation (forests, mixed forests and shrubs), in blue herbaceous covers, in black the agricultural, bare and urban areas, and in white the water. The numbers, to be referred to in Table 1, indicate the locations of the validation sites. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

is detected by a snow free record, using MODIS data. Alternatively, the onset of greening has been estimated as the date at which NDVI exceeds a threshold. Suzuki et al. (2003) consider that the budburst occurs when the NOAA NDVI exceeds 0.2, assuming that above this threshold snow is not present. White et al. (2005) consider that removing the snow effects from the signal is of primary importance for the analysis of phenological variations from NDVI.

In a previous paper, a method was proposed to retrieve the date of onset of greening using a remote sensing index (different from NDVI) which excludes snow effects (Delbart et al., 2005). The index used in this method is a combination of near and middle infrared reflectances. Such combination was proposed by Hardisky et al. (1983) and was adapted to the SPOT-VEGETATION (VGT) spectral bands by Xiao et al. (2002) under the name of Normalized Difference Water Index (NDWI), first proposed by Gao (1996) to designate a slightly different spectral index. The detection algorithm by Delbart et al. (2005) relies on the fact that NDWI first decreases with snowmelt and then increases during the vegetation greening. The method (referred to as the NDWI-VGT method) was applied to VGT data from 1998 to 2002 over central Siberia and its results agreed well with in situ dates of leaf appearance. The RMS error over 19 data points was of 8.7 days and the bias, 0.7 day, whereas using NDVI, the RMSE were about 9.7 days and the bias, non-uniform spatially, varied from 5.6 days to more than 10 days. Both methods could give equivalent results in the trend analysis, however, only the NDWI-VGT method can provide an accurate and precise determination of the dates of onset of greening (Delbart et al., 2005).

Long time series of accurate and precise spring phenology dates cannot be provided by neither VGT, which has been operating since 1998, nor NOAA-AVHRR which does not have the equivalent middle infrared band needed for the NDWI method. To make use of the long time series of NOAA-AVHRR, the alternative proposed in this paper consists of using NDWI-VGT results from 1998 to 2001 to determine pixel specific thresholds (PST) from NOAA-AVHRR NDVI time series. The PST value is then the NDVI value at which onset of greening is expected to occur for all years at a particular pixel. The method (referred to as the PST-NOAA method) is applied to the 1982–2001 Pathfinder AVHRR Land (PAL) NDVI dataset, on a large area in Northern Eurasia. The greening-up dataset is then constructed from 1982 to 2004, using PST-NOAA results for 1982–1997 and NDWI-VGT results for 1998–2004. All results are compared to in situ dates of leaf appearance from eight validation sites. The temporal evolution of spring phenology in the study area since 1982 to present is analysed. Finally, the method is discussed in regard to the sources of uncertainty, the calculated trends in phenology are compared with those from other studies, and the significance of our results for carbon budget calculation is discussed.

2. Study area and data

2.1. Study area

The study area is in northern Eurasia, located between latitudes 50°N and 72°N and longitudes 45°E and 180°E. Fig. 1 shows the land cover map of the study area, adapted from the Global Land Cover 2000 (GLC 2000) map (Bartholomé & Belward, 2005) to highlight evergreen and deciduous vegetation covers, and herbaceous covers in the North (tundra) and South (steppe). Bare areas and agricultural covers are not considered in the study and are shown in black. Fig. 1 shows that deciduous vegetation covers a large proportion of the area, in particular at latitudes beyond 90°E, where the main tree species is larch.