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Comparing land surface phenology with leafing and flowering observations from the PlantWatch citizen network

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ABSTRACT

Annual maps of the remote sensing green-up date derived from SPOT-VEGETATION data were compared to the phenological observations collected by the PlantWatch citizen science project across Canada between 1998 and 2012. Green-up dates were found to relate to the leaf-out dates for four woody species (*Populus tremuloides*, *Acer rubrum*, *Syringa vulgaris*, *Larix laricina*), with a RMSE from 13.6 to 15.6 days. This was true for all landcover types except in pixels where agriculture or water bodies were dominant. This is less accurate than the results from previous studies for boreal Eurasia (RMSE = 8.7 days), with phenology data from an operational network. When data were aggregated at a regional level, the remote sensing green-up date matched well with the interannual variations in leafing and also in flowering of most of the recorded species. These included spring events for trees, shrubs and non-woody plants which were either native to Canada or introduced. For most plants, spring flowering and leafing times are functions of accumulated temperature. For this reason, plant species develop in a predictable sequence, and interannual variations in this cohort of species leafing and flowering are correlated. This explains the correlation with remote sensing green-up. Data from this volunteer PlantWatch network proved consistent with independent satellite data, suggesting that combining the two will strengthen the future capacity to monitor vegetation changes.

1. Introduction

Phenology is both a response to and a driver of global changes (Richardson et al., 2013). Besides reflecting the impact of climate change (Badeck et al., 2004; Parmesan & Yohe, 2002; Root et al., 2003; Walther, 2010; Walther et al., 2002), phenological shifts affect the functioning of ecosystems (Baldocchi, Falge, Olson, et al., 2001; Both, Van Asch, Bijlsma, Van Den Burg, & Visser, 2009; Chuine, 2010; Picard et al., 2005). Phenological changes and gradients have been assessed through a variety of methods, including ground observations carried out by scientists (Ahas, Aasa, Menzel, Fedotova, & Scheifinger, 2002; Menzel, Sparks, Estrella, et al., 2006; Schwartz, 2013) or by citizens interested in nature (Beaubien & Hamann, 2011a and b; Gazal et al., 2008; "http://obs-saisons.fr"), modelling (Chuine, 2000; Hänninen, 1994; Morin et al., 2009; Schwartz, Ahas, & Aasa, 2006), or remote sensing based methods. Remote sensing methods are used to estimate green-up, also called "land surface phenology", *i.e.* the timing of changes at the scale of a satellite pixel (Reed et al., 1994; Sakamoto et al., 2005; Zhang et al., 2003). Satellites can observe the earth surface frequently enough – if cloud conditions allow it – to catch the gradual changes in the reflectance, and satellite images are available starting in the early 1980s (Moulin, Kergoat, Viovy, & Dedieu, 1997).

During the boreal or temperate spring, the remote sensing green-up date is usually defined as the time at which the pixel starts to green-up or has reached a certain percentage of its maximum summer greenness. Greenness is quantified through a spectral vegetation index combining the reflectance retrieved from the observed radiance in the near infrared domain and in one visible band, based on the absorbance spectrum of chlorophyll. This vegetation index increases as the amount of photosynthetic tissue increases within a pixel. Methodologies to derive the green-up date from these index time series are numerous and can give very different results (White, De Beurs, Idan, et al., 2009). Validation of the green-up date therefore requires a comparison with external data, typically ground observations of plant phenology. Ganguly, Friedl, Tan, Zhang, and Verma (2010) showed that the MODIS collection 5 global green-up product compared well with ground observations at two sites. White et al. (2009) however showed that eight out of ten tested methods gave green-up dates that were very different from ground observations. Ideally, linking phenological observations made on individual plants to green-up dates requires that the observed individuals are representative of their surroundings up to the pixel size.

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This is challenging when the area within the pixel contains a mosaic of land cover types, or when species diversity is high, or when there is a pronounced phenological diversity among individuals of the same species in the pixel. Methods to overcome such drawbacks include reducing the pixel size (Fisher, Mustard, & Vadeboncoeur, 2006; White, Pontius, & Schaberg, 2014), cross-comparing results obtained at different spatial resolution (Fisher & Mustard, 2007), or increasing the number of ground observations within the pixel (Liang, Schwartz, & Fei, 2011).

Delbart, Kergoat, Le Toan, L'Hermitte, and Picard (2005) described a method based on SPOT-VEGETATION reflectance data to estimate the green-up date in boreal regions without the confusion due to reflectance changes during snowmelt. The method uses the Normalized Difference Water Index (NDWI), which is the normalized difference of near infrared (NIR) and short-wave infrared reflectance (SWIR). This index is sensitive to the water content in the plant tissues rather than to chlorophyll (Gao, 1996), and increases during foliation. The green-up dates were compared to ground measurements of deciduous tree leaf appearance date for ten taiga sites in Siberia, showing a root mean square error (RMSE) of 8.7 days. This validation was based on the hypothesis that the Siberian taiga was homogeneous enough in terms of phenology within the SPOT-VEGETATION pixel, due to the large forest fractional cover and to the small number of tree species, to make the field observations representative of the whole pixel in which they were made. The method was further tested at a few more sites in other parts of boreal Eurasia (Delbart et al., 2008) and to one site in Alaskan tundra (Delbart & Picard, 2007). In both cases, the confidence in the green-up date was increased by the agreement found with the date obtained not only by local observation but also by a degree-day model based on daily temperature. Delbart et al. (2008) showed that the green-up date averaged at the regional scale reproduces a large part of the interannual variation in leafing date observations carried out at several locations within the region.

Still, remote sensing methods hold an inherent drawback in that they do not reveal the diversity of plant phenology within the pixel. Diversity comes from the phenological differences between species (interspecific variation) and between individuals of the same species (intraspecific variation). Moreover, as vegetation indices are usually based on spectral signatures that are explained by chlorophyll, and because usually leaf tissue mass is much larger than flower tissue mass, we can assume that green-up – either retrieved from a greenness index or from NDWI – is essentially directly linked to foliage phenology. It may also be indirectly linked to flower phenology, as both spring foliage and flowers develop in response to increasing temperature and thus are correlated to each other.

The objective of this study is to evaluate how the green-up relates to both the leaf and flower phenology of the diverse plant species within the pixel. For this, we carry out a comparison of the green-up date with 743 observations of the date of leaf appearance made on four tree species and several thousand observations of the date of first flowering for 39 species. This large set of phenological observations was collected by Canadian citizens in the framework of the PlantWatch project following a precise protocol (Beaubien & Hamann, 2011a and b; www.plantwatch.ca). We further evaluate if green-up can be used to monitor the interannual variations of plant leafing and flowering dates efficiently.

2. Materials and methods

2.1. SPOT-VEGETATION NDWI estimates of green-up dates, 1998–2012

The algorithm described in Delbart et al. (2005) is applied to the SPOT-VEGETATION (VGT) S10 data for the years 1998 to 2012 (freely available at http://www.vito-eodata.be/PDF/portal/Application.html). S10 data gives a reflectance value for four spectral bands once every ten days. The selected value is the "best" measurement that has been made during the 10 day period, following the "maximum value composite" method (Holben, 1986). The exact date of the selected measurement is given individually for each pixel.

The objective of our method is to provide an estimation of the date on which the ecosystem greens up. To avoid false detection due to snowmelt, the green-up date is retrieved from the seasonal evolution of NDWI as this index decreases during snowmelt and increases during foliage development. Green-up date is taken as the last date in the March–July period at which NDWI has increased by less than 20% of its total increase in this period. Here, the algorithm is applied at the full VGT spatial resolution (0.0089°). The algorithm is run for the years 1998 to 2012, to obtain one green-up day map each year.

2.2. PlantWatch observations and land cover map

The phenological observations are carried out and reported in the database by citizen scientists in the framework of the PlantWatch project (*www.plantwatch.ca*). We use *in situ* first-bloom data for 39 species (Table 1), and leaf-out data for four selected woody plants *Acer rubrum*, *Syringa vulgaris*, *Populus tremuloides* and *Larix laricina* (see spatial distribution in Fig. 1). The description of all species and their observation protocols can be found on the PlantWatch website. Data were quality checked: the observations reported from the Churchill Northern Studies Centre project to the PlantWatch database were discarded because of issues with geographic coordinates and some taxonomic errors.

The data are stratified according to the GLC2000 landcover map (Bartholomé & Belward, 2005), which provides 22 classes (simplified in Fig. 1). This dataset was derived from SPOT-VEGETATION time series

Table 1
Scientific and common names of the species observed in the PlantWatch project and used in this study.

Scientific name (* are introduced species)	Common name
Acer rubrum	Red Maple
Achillea millefolium	Yarrow
Amelanchier	Saskatoon or Serviceberry
Anemone patens	Prairie Crocus
Arctostaphylos uva-ursi	Bearberry
Betula papyrifera/B. neoalaskana	Paper Birch
Clintonia borealis	Blue-bead Lily
Clintonia uniflora	Queen's Cup
Cornus canadensis	Bunchberry
Dryas integrifolia, D. octopetala	Mountain Avens
Elaeagnus commutata	Wolf Willow
Epigaea repens	Mayflower
*Forsythia suspensa**	Weeping Forsythia
Fragaria virginiana/F. vesca	Wild Strawberry
Galium boreale	Northern Bedstraw
Houstonia caerulea	Bluets
Larix laricina	Larch
Linnaea borealis	Twinflower
Lupinus arcticus	Arctic Lupine
Maianthemum stellatum	Star-flowered Solomon's Seal
Myrica gale	Sweetgale
Nymphaea odorata	White Water Lily
Pinus contorta	Lodgepole Pine
Populus tremuloides	Aspen Poplar
Prunus virginiana	Choke Cherry
Ranunculus glaberrimus	Sagebrush Buttercup
Rhododendron canadense	Rhodora
Rhododendron groenlandicum	Labrador Tea
Rubus chamaemorus	Cloudberry
Saxifraga oppositifolia	Purple Saxifrage
Saxifraga tricuspidata	Prickly Saxifrage
*Syringa vulgaris**	Common Purple Lilac
*Taraxacum officinale**	Dandelion
Thermopsis rhombifolia	Golden Bean
Trientalis borealis	Starflower
Trillium grandiflorum	Trillium
*Tussilago farfara**	Coltsfoot
Vaccinium vitis-idaea	Cranberry
Viola adunca	Early Blue Violet

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