Forest health monitoring system in Hungary based on MODIS products

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Abstract

Ground-based forest observations in Hungary have recently been completed by a wall-to-wall system (in Hungarian: "TEMRE") to monitor forest health in relation to environmental changes (including climate change). The system is based on free images from the MODIS sensor of the Terra OSM satellite. Once in every 16 days during the vegetation season, NDVI values are automatically downloaded, masked for the Hungarian forest area, filtered for errors, and classified using standardized NDVI-index values. Maps are regularly published in a 250*250 m resolution at www.klima.erti/TEMRE.php. The attribution of discolorations, to be attempted for larger (>1000 ha) contiguous areas, is supported by tree species map layers (currently) and site factors (under development). The paper demonstrates some results of the analysis of images from recent years.

Introduction

Forest health has increasingly been a concern in Europe since the 1980s when air pollution caused extensive forest damage (Sanders et al. 2016). While critical loads are still being exceeded (Seidling, 2016), new concerns have been raised over the possible effects of climate change and the increasing concentration of CO_2 in the air on forests (Loehle, 2016, Pluess et al. 2016, Ramsfield et al., 2016, Settele et al. 2014, Trumbore, 2016). These effects might include forest dieback that can significantly increase greenhouse gas emissions (Allen et al, 2010, Somogyi, 2016), providing positive feedback to climate change itself. The need to avoid this and other adverse phenomena in forests makes it important to intensify forest health monitoring and increase efforts to better understand environ1mental effects on forest.

Forest health has been monitored in Hungary for decades (NÉBIH, 2009, Hirka, 2017). Over the years, the methods of the monitoring were developed to also meet requirements of international programs such as the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (IPC Forests) (Sanders et al., 2016) and Forest Europe (2005).

The main components of the current monitoring system are the following: (i) permanent plots (NÉBIH, 2009) where observations and causation are made following internationally agreed methods (ICP Forests Manuals, 2017), (ii) forest owners' and forest managers' reports (required by the Hungarian Forest Act) on larger-scale occurrence of pests and pathogens (the results of these reports are published on maps, see at http://erdoterkep.nebih.gov.hu/erdokar/index.htm), (iii) a forestry light trap system and (iv) many dedicated research projects (Hirka, 2017).

To monitor the potential effects of climate change on the entire forest area, while also meeting demands by both the forestry practice and the forest research community, the above system has recently been completed by a remote sensing-based, wall-to-wall system ("Távérzékelésen alapuló Erdőállapot Monitoring Rendszer", TEMRE). Such systems already exist in many countries (Lausch et al., 2016, 2017) including neighbouring countries such as Slovakia (see at http://www.nlcsk.sk/stales/klasdynam_en.html). This paper presents a summary of TEMRE and some preliminary results of its application.

System summary

The main source of information for TEMRE is the freely available and regularly published satellite products of the MODIS sensors of the NASA Terra satellite that detect atmospherically-corrected reflectance in 36 spectral bands at a medium spatial resolution (250 m) but with high frequency (in intervals of 1-2 days, Justice et al. 2002). TEMRE makes use of the Normalized Difference Vegetation Index (NDVI) composite (see below) that is produced, since the year 2000, from the best quality pixel values in 16-day cycles (with pictures on the same date each year).

TEMRE produces maps in a fully automatic procedure using a proprietary software written in R (2018). First, new pictures are downloaded from the LAADS NASA server (ftp://ladsftp.nascom.nasa.gov/) during the vegetation season (i.e., end of April till end of September) once they become available. Then, using a recent forest cover mask, pixels are clipped that have a forest cover of at least 75% (currently, 241830 pixels). The pixels are then filtered for errors using the quality codes included in the composites (pixels classified as "unuseful", or with mixed clouds, cloud shadow, possible snow/ice cover and high aerosols are excluded).

NDVI is calculated from near infrared (NIR) and visible red (RED) intensities as detected by the satellite sensors the following way:

$$NDVI = \frac{NIR-RED}{NIR+R} \qquad (1)$$

NDVI at any moment indicates the photosynthetic activity of the forest canopy. Its values can vary between -1 (at low activity) and +1 (at high activity). NDVI is especially applicable to detect leaf loss and discoloration (Caccamo et al. 2011, Spruce et al. 2011, Hlasny et al. 2014) which is usually extensively registered in ground-based surveys, too. However, due to the above algorithm, index values and photosynthetic activity are non-linearly related, and the sensitivity of the index values is reduced (due to saturation) in forests of high biomass (Huete et al. 2002). Moreover, the absolute intensity of photosynthetic activity itself depends on the actual vegetation season and many other factors with inter-annual variation. If such factors affect large areas, a simple spatial comparison of absolute intensity values would not be enough to detect health issues. Therefore, as a key element of our system to reduce this inter-annual variation, we standardize NDVI values over time in the next step using the following formula (Peters et al., 2002):

$$Z_{NDVI} = \frac{NDVI-\overline{NDVI}}{\sigma_{NDVI}} \qquad (2)$$

where Z_{NDVI} is the standardized NDVI, $\overline{NDVI}$ is the multiple-year average of NDVI, and σ_{NDVI} is the standard deviation of NDVI values, where $\overline{NDVI}$ and σ_{NDVI} are calculated for a given 16-day period of the year from values for a period beginning with the first year with available data (i.e., 2000) and ending with the most recent year. Less than zero Z_{NDVI} values, i.e. where the actual NDVI value is less than the long-term average, might indicate a forest health issue.

As a last step of the automatic procedure, raster maps of Z_{NDVI} values are published at www.klima.erti/TEMRE.php over a base map using Geoserver (http://geoserver.org/) and the following colour-codes: <-2 (deep red); -2 – -1 (orange); -1 – 0 (yellow); 0 – +1 (light green); >+1 (dark green).

In itself, a reddish or red Z_{NDVI} value is usually not enough to conclude that the forest under the pixel has developed a health issue, let alone what that issue might be. Discolouration can occur due to a number of reasons even in healthy areas including measurement errors; local and temporary atmospheric phenomena that could not be filtered out as error in the above process; a temporary drop of the photosynthetic activity of healthy trees; and forestry operations such as harvesting (about 1% of all forest area of Hungary a year) and forestation.

Discoloration of pixels of forests with health issues can be due to lasting physiological deficiencies (caused by factors such as drought, heat stress, lack of nutrients and biotic agents) or abrupt leaf area loss (caused by pests, late frost, strong wind etc.). In both cases, a sequential analysis of the pixel values might provide clues as to whether a forest health issue can be suspected.

The extent of the discoloured pixels might provide clues to possible causes. The number of pixels in the TEMRE maps is large, and individual pixels can change their colours due to many reasons. Currently, we suggest to only analyse a more-or-less contiguous discoloured group of pixels covering a minimum of about 1,000 ha.

In any event, TEMRE, which might show the location(s), severity and extent of new issues, might suggest ad-hoc observations in the ground.

When assessing the possible causes of forest health issues, the analysis of forest or environmental characteristics can be of importance. Data on drought (see e.g. http://vegdri.unl.edu/), temperature, precipitation, extreme events, elevation, aspect, soil information, soil water, forest operations and other local information should complete remote sensing information. Currently, only species information is published on the TEMRE website, but publishing other layers is under preparation, and important meteorological information can be found at http://www.met.hu/idojaras/aktualis_idojaras/napijelentes/.

Preliminary results

The above system was operated in a trial period in 2017. Experience has shown that the system can monitor most of the forest area of Hungary and detect forest health issues across space and over time. As an example, TEMRE could easily detect the effects of the large-scale sleety rain (glaze) that loaded trees with heavy ice in Pilis and Börzsöny mountains in North Hungary 1-3 December 2014. This disturbance was the largest ice-break since 1965 (Hirka 2017) and severely damaged 9200 ha of forests (Csépányi et al 2017). Pixels over the damaged areas showed discolouration through 2015 in rather distinct areas. Reduced activity areas in the same regions could also been seen in 2016 when discolouration started to disappear due to regeneration and forestation. The discolouration was further reduced in 2017 (Figure 1).

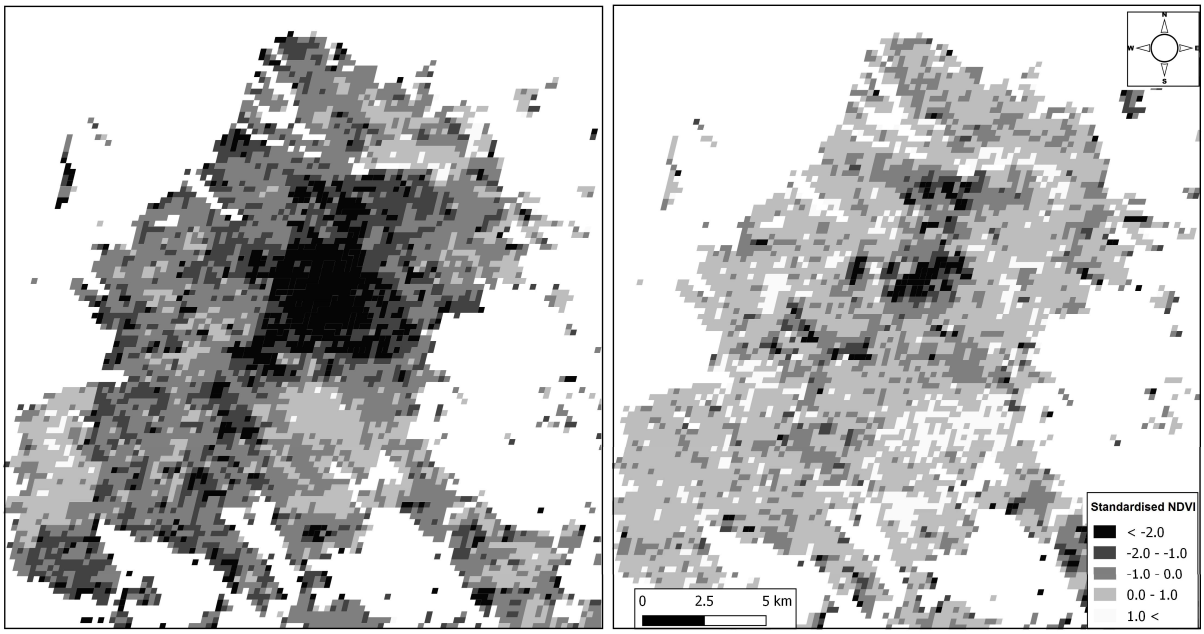

Figure 1. Discolouration of the forests in the Börzsöny mountain (central north Hungary) mid-July 2015 (left) and 2017 (right), after a large-scale icebreak in December 2014.

A more recent event happened early 2017 when spring frost, snow and wind damaged some mountainous areas above about 400 m a.s.l., however, discolouration gradually disappeared in May and June. In July and August 2017, damage by different pests (later identified by observations in the ground) in North-eastern mountains and in sandy flat plains of Hungary could well be identified on the maps, too.

All these and other results demonstrate that the MODIS NDVI products can be successfully used in forest health monitoring when combined with information collected in the ground. The system will be developed based on current and future experiences, while developing similar systems using e.g. Sentinel products is also planned.

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