Studying vegetation dynamics in Central Europe using MODIS and meteorological data: The effect of drought on the vegetation state

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Abstract

Vegetation related researches at the Space Research Group of the Eötvös Loránd University (Budapest) during the last years were based on the Direct Broadcast data of the operated receiving station, and on a variety of vegetation related official products derived from remote sensing data. The main data source for the researches is the data of the MODerate resolution Imaging Spectroradiometer (MODIS) on board satellites EOS-AM1/Terra and EOS-PM1/Aqua.

To characterize vegetation dynamics affected by the climate during the 2000-2016 time period within the Carpathian Basin, in Central Europe, several quantities were used: from the simplest and most commonly used indices (like the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI)), through the more complex indices (like the Leaf Area Index (LAI) and the Fraction of Absorbed Photosynthetically Active Radiation (FPAR)), to the more sophisticated methods (such as the model of Gross Primary Production (GPP), and Net Primary Production (NPP)). The above mentioned NDVI, EVI, LAI, FPAR, GPP and NPP are all derived from the data of the MODIS sensor, and are disseminated by the National Aeronautics and Space Administration (NASA) as official MODIS products.

Our researches revealed a clear relationship between the weather and the state and productivity of the vegetation, where the effect of the climate variability is strongly depending on the plant functional type. Within the frame of these researches we are also focusing on the effect of the extreme weather events, such as droughts and heatwaves. Droughts and heatwaves affect all plant functional types, but the response of the vegetation is not uniform and depends on other parameters, plant strategies and the antecedent meteorological conditions as well. To discriminate the different behaviour of the various plant functional types meteorological (FORESEE) and land cover (MCD12 and CLC2012) databases were also used.

Aim

The aim of the research was to investigate the relationship between the anomalies of meteorological parameters (such as precipitation and temperature) and the vegetation related characteristics (principally NDVI) during the recent years of 2000-2016 for the Carpathian-Basin in Central Europe, based on the response of the vegetation.

Additionally, we distinguished the effects of weather anomalies for areas with high and low climate variability, to test our hypothesis, that vegetation on areas with higher climatic variability are less prone and less sensitive to the extreme weather events due their better acclimatization.

What are the effects of the extreme weather on the vegetation?
Can we identify differences between responses of plants in terms of sensitivity?

Approach:
1. Select pixels from the country, which are representative for the mean climate of that country.
2. Distinguish them based on high and low weather variability.
3. Use them to study the effect of extreme meteorological parameters on different land cover types.

Materials and Methods - MODIS data

To study the response of the vegetation we used the latest version (Collection 6) of MODIS NDVI, EVI, FPAR, LAI, GPP, and NPP with 500 × 500 m spatial and 8-days temporal resolution covering the 2000-2016 time period, as part of the MOD13A1, MOD15A2H, MOD17A2H and MOD17A3H official MODIS products, derived from the measurements of the MODIS sensor on board satellite Terra. Quality filtering of each dataset was performed using the quality flag information included in the datasets based on the work of Kern et al. (2016). We also applied the BISE smoothing (Viovy et al., 1992) for NDVI and EVI (MOD13) to create a dataset with 8-day temporal resolution.
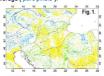
Materials and Methods - Land cover database

Land cover specific anomalies of the meteorological and vegetation characteristics were created and averaged on a country-scale, where the distinction between the main land cover types were based on the synergetic use of MODIS land cover and Coordination of information on the environment (CORINE) Land Cover 2012 datasets, to identify pixels with high probability of being broadleaf forests, coniferous forests, croplands and grasslands.

From the MODIS MCD12Q1 land cover we used the Type-1 (International Geosphere Biosphere Programme - IGBP) to identify croplands and grasslands and the Type-3 (MODIS-derived LAI/fPAR scheme) classifications for broadleaf and coniferous forests to select pixels with unchanging land cover ("stable pixels") during the period of 2001-2013.

From the CORINE classification the CLC classes 211, 212, 213, 241 and 242 were categorized as croplands, 231 and 321 as grasslands, 311 as broadleaf forests and 312 as coniferous forests to select pixels with at least 90% coverage ("pure pixels").

Using the derived set of MODIS stable pixels and CORINE pure pixels we selected reliable pixels which were classified by both land cover database to the same vegetation type of broadleaf forests, coniferous forests, croplands and grasslands (Kern et al., 2017). Fig 1 shows the location of the remaining reliable pixels of the main land cover types based on MODIS IGBP (MCD12 Type-1), LAI/FPAR scheme (MCD12 Type-3) classifications and CLC2012 database, being constant during the study period and having probably right classification.

Fig. 1.

Broadleaf forest   Coniferous Forests   Croplands   Grasslands

Materials and Methods - Meteorological data

To investigate the effect of the weather on the vegetation activity and greenness, we used the FORESEE meteorological database (Dobor et al., 2015). The FORESEE database is based on the E-OBS observations and contains daily precipitation and daily minimum and maximum temperature data with 1/6°×1/6°grid resolution for Central-Europe. Resampling of the original database to the sinusoidal grid of the MODIS products with 1km resolution with DEM-correction was performed based on Kern et al. (2016).

From the daily data we calculated yearly anomalies relative to the mean of the period of 2000-2016, both for the whole year (to Fig. 7-10), and also only for the growing season (from May to August, to Fig. 13-24).

Fig. 2 and 3. Resampled mean temperature and precipitation fields (respectively) calculated for the entire domain area of the FORESEE v2.1 database for the study period of 2000-2016.

① **Representative areas** were determined as the areas with highest representativity (upper 10 percentiles of the country, presented in Fig. 4.), calculated based on the percentiles of relationships (R², RMSE, bias) between:
- monthly meteorological data, and
- the interannual average of the area,
where the mean temperature and precipitation were handled together.

Fig. 4. Representativity map of Hungary based on temperature and precipitation for the study period of 2000-2016. Areas with higher (darker) values correspond to higher representativity relative to the mean of the country.

② Pixels of the sensitivity study were selected from meteorologically representative areas using the standard deviation of the meteorological parameters (during the 17 years of the study period) **to distinguish areas with low and high climate variability.** For broadleaf forests and croplands 25 and 75 percentiles, for grasslands 5 and 95 percentiles were used.
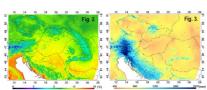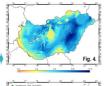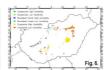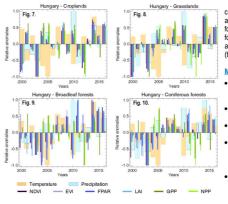

Selected pixels from the most representative areas based on the standard deviation of temperature (Fig. 5) and precipitation (Fig. 6).

Characterization of the years between 2000-2016

Temperature   Precipitation
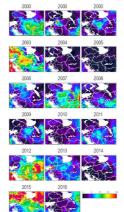NDVI   EVI   FPAR   LAI   GPP   NPP

Yearly relative anomalies of the vegetation related characteristics (such as NDVI, EVI, FPAR, LAI, GPP, and NPP) during 2000-2016 are presented in **Fig. 7-10** for croplands, grasslands, broadleaf and coniferous forests for Hungary. The yearly, land cover specific anomalies of the meteorological variables (temperature and precipitation) are also presented.

Main findings:
- quite consistent for croplands and grasslands, showing the same direction of relative anomaly in most of the cases,
- forests reveal different behaviour, not showing similarity in the anomalies,
- GPP and NPP show opposite character for some years compared to other indexes (! model),
- not only the yearly anomalies of the meteorological parameters that affect the plant status, but the within-year temporal pattern of the meteorological elements,
- complex system: depending also on the soil moisture, radiation, depth of the root-zone, storage from previous years (carbohydrate reserves).

Pálfai Drought Index during 2000-2016
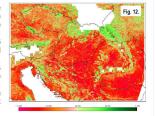

Fig. 11.

The Pálfai Drought Index (PDI, Pálfai et al., 2011) were calculated for each year during the study period of 2000-2016 (Fig. 11), using daily temperature and precipitation data at the original grid of the FORESEE database (1/6°×1/6°).

The PDI reflects the temperature conditions during the April-August period, and the precipitation conditions during the October-September period. It also takes into account the number of the heat days (based on the daily maximum temperature), and also the number of the rainless days during the given year. (Higher PDI reflects year with stronger droughts).

The spatial appearance of droughts are varying, although the years with heavy droughts in the Carpathian Basin (2003, 2007, 2012) can be recognized.

R-values calculated from the linear regression between the yearly NDVI anomalies of the growing season and the yearly PDI during the period of 2000-2016 were calculated at pixel level (Fig.12).

Red areas reveal an obvious negative relationship between the strength of droughts and the NDVI anomalies, while forests (green areas) show a much complex behaviour.

Fig. 12.

The sensitivity of plant state to meteorological anomalies

To study the effect of extreme weather events on the vegetation state, land covers specific scatter plots (Fig. 13-24) of:
- meteorological anomalies
- versus NDVI anomalies

during the growing season were created, separately for the areas of high, and low climatic variability during the period of 2000-2016 (where the number of the pixels are indicated on the figures). Each year is indicated by different color.

The results reveal that:
- the response of croplands and grasslands to climate anomalies is linear,
- areas with lower climatic variability show stronger response to the extreme weather events, especially in case of grasslands,
- in case of the forests there is no obvious response due to their different behaviour and complexity (soil-water-plant relations and legacy effects of previous periods); with more plausible quadratic fitting instead of simple linear regression (especially in case of temperature).

Without considering representativity
(indicated by blue values):
- lower R values,
- decreasing difference between regression slopes of the areas with high and low climate variability.

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

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