Retrospective analysis of long-term landscape evolution based on archive satellite imagery

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ABSTRACT
This study deals with the long-term retrospective analysis of the evolution of landscape features by exploiting the potential of long-term archive optical satellite imagery time series. Resulting temporal trajectories and disturbance/stability features are then used as an input to assess the current state of local ecosystems.

INTRODUCTION
Major help in tracing back the history, dynamic and trends of Earth surface features, revisiting processes (1)(2):
• the opening of large satellite archives (e.g. the Landsat archive),
• enormous progress in computation, novel processing techniques,
• important amount of thematic and historical maps possibly dating back to hundreds of years [3][4].

Fig. 1. Landsat 5 TM false colour compositions of the study area (bands 4,5,3 RGB)
Landsat 8 OLI false colour compositions of the study area (bands 5,4,8 RGB)

Our assumption is that the impact of land cover / land use changes tied to some historical moments can be extracted from remote sensing data.

OBJECTIVES
In the frame of the European Biodiversity Strategy 2020 a project recently started in Hungary for mapping and assessing the current state of ecosystem services and elaborating methods for their future monitoring. Remote sensing is applied for ecosystem mapping and status assessment:
• extract and analyze landscape changes recorded in EO data sets
• reveal the past and assess the stability of landscape objects of multiple types
• changes in the spatial structure of land cover and land use are of particular interest (including linear elements: corridors, barriers)
• provide processed data for subsequent analysis and methodology for follow-up monitoring.

A. Study area
Located in the central part of Hungary (Kunbaracs area, 50 x 50 km), selected due to its representativeness and complexity: woodlands, grasslands, agricultural and urban areas are all present.

B. Satellite imagery
• Archive Landsat Collection 1 surface reflectance downloaded from USGS EarthExplorer ([https://earthexplorer.usgs.gov/]
• Completable ESA EarthNet Level 1 scenes ([https://landat.esa.int]) — surface reflectance and cloud mask calculated
• 57 images taken in the summer period (preferably in August) from 1994 to 2016
• multiple overlapping periods for intercalibration of different sensors.

RESULTS & DISCUSSION
A. LandTrend
• Fitted temporal trajectories for each pixel (vertex years and values, change magnitudes, and segment lengths, etc.)
• Change labeling provided thematic outputs (years and magnitudes of most recent and greatest disturbances, disturbance intervals, revegetation rate and many others).
• LandTrend can perform well on forested areas (as this is its main purpose), less efficient in grasslands, no meaningful results in agricultural areas.

B. PCA-based stability metrics
• Binary change / no change maps for each consecutive image pair calculated
• A “stability score” obtained for each pixel after summarizing the change maps over the period 1994–2016. “Stability score” shows the number of times the pixel has been selected as invariant over the cloud-free acquisitions (Fig. 4.)

METHODS
A. Time-series construction
• Landsurface Reflectance products (USGS) were used directly in data processing chain
• Surface reflectance and cloud mask for Level-1 scenes from ESA EarthNet were calculated using LEDAPS ([https://github.com/USGS-eros/eros-surfacedata/reflectance/tree/master/ledaps]) and CMask ([https://github.com/USGS-eros/eros-cloud-masking]).
• LandsatLink package ([https://github.com/btkh/landlink]) was used for preprocessing images prior to running LandTrend.

B. Long term analysis of spectral trajectories with LandTrend
Long-term analysis by a specific variant of LandTrend [2]: LLL-LandTrendr ([https://github.com/btkh/landlink/landtrendr]) that can work directly on the results of LandsatLink. Disturbance metrics are of principal interest to assess the long-term stability and its influences on the state of local ecosystems.

C. Spectral stability assessment by accumulated bi-temporal PCA-based change detections [5]
• Principal Component Analysis (PCA) executed over all consecutive image pairs to generate binary change/no change maps
• Change maps summarized over different time periods to provide cumulated stability maps.
• Cloud masks used to identify pixels with no valuable data for each acquisition.

D. Monitoring changes in spatial patterns of land use
High-pass filter (HPF) with 3 x 3 kernel was executed on NDVI maps of each acquisition date to assess structural changes in land use and land cover.
• HPF has enhanced edges and linear structures and erased spatial information as it was expected and needed
• Resulting images were averaged over time to assess the stability and monitor the changes in spatial land use structure (including linear elements) over time. Periods and key dates behind land use process:
  - 1984-1991: Fall of the social regime
  - 2001-2016: (2004 EU membership, agricultural subsidies accessible)

CONCLUSIONS
1. Construction of long-term Landsat surface reflectance annual time series by the combination of NASA/USGS and ESA archives is possible.
2. Preprocessing supported by LEDAPS, data preparation by LandsatLink
3. LandTrend provides a tremendous amount of information, very useful for forested areas, less suitable for grasslands and no trends in agriculture. Further optimization of parameter settings is needed.
4. Bitemporal PCA-based invariant mapping executed over the time series provided tangible stability scores.
5. Changes in spatial structure of land use and linear landscape elements were successfully emphasized and tracked by HPF filtering and its temporal aggregation.

REFERENCES

Fig. 2. Map of stability scores summarized over the period 1994-2016. Bright colours indicate stable areas.