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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, revealing 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].

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/)
- Complementary **ESA EarthNet Level 1 scenes** (https://landsat-ds.eo.esa.int/) → surface reflectance and cloud mask calculated
- 37 images taken in the summer period (preferably in August) from 1984 to 2016
- multiple overlapping periods for intercalibration of different sensors.

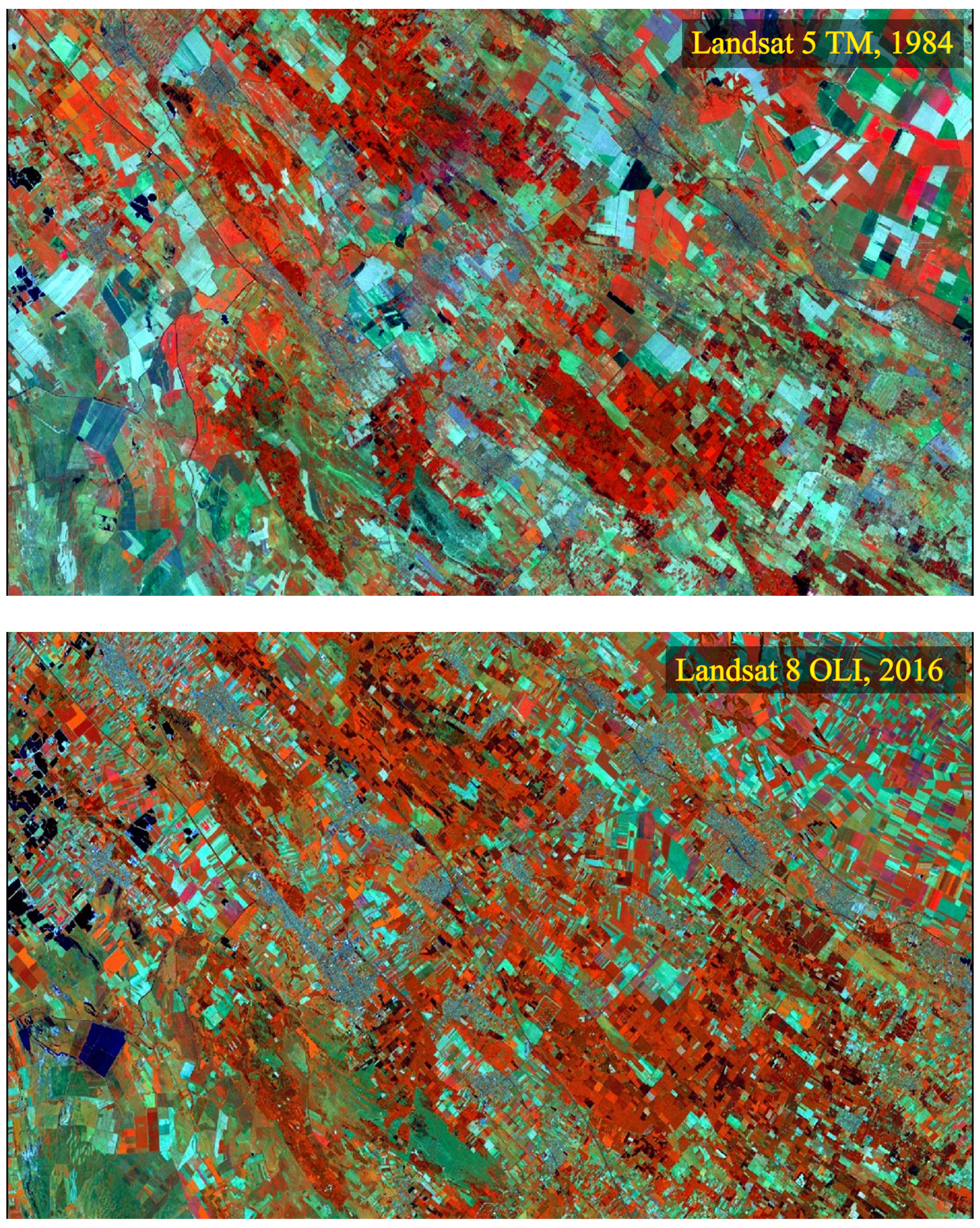


Fig. 1.
Landsat 5 TM false colour composites of the study area (bands 4,5,3 RGB)
Landsat 8 OLI false colour composites of the study area (bands 5,6,4 RGB)

C. Ancillary data

- CORINE land cover maps (1990, 1998, 2000, 2006 and 2012)
- Detailed habitat maps (ÁNÉR) created in the frame of the National Biodiversity Monitoring System and the Natura network.

METHODS

A. Time-series construction

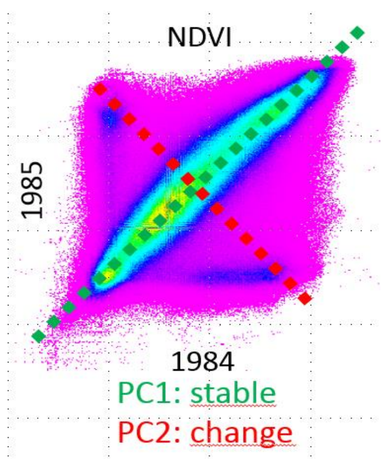
- Landsat Surface Reflectance products (USGS) were used directly in data processing chain
- Surface reflectance and cloud mask for Level-1 scenes from ESA EarthNet were calculated using LEDAPS (https://github.com/USGS-EROS/espa-surfacereflectance/tree/master/ledaps) and Cfmask (https://github.com/USGS-EROS/espa-cloud-masking).
- **LandsatLinkr package** (http://landsatlinkr.jdbcode.com/) was used for preprocessing images prior to running LandTrendr.

B. Long term analysis of spectral trajectories with LandTrendr

Long-term analysis by a specific variant of LandTrendr [2]: **LLR-LandTrendr** (https://github.com/jdbcode/LLR-LandTrendr) that can work directly on the results of LandsatLinkr. 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 spectral 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 (1989: fall of the socialist regime)
  - 1992-2000 (changes in land ownership – privatization process)
  - 2001-2016: (2004: EU membership, agricultural subsidies accessible)

RESULTS & DISCUSSION

A. LandTrendr

- 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).
- LandTrendr 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 1984-2016. „Stability score" shows the number of times the pixel has been selected as invariant over the cloud- free acquisitions (Fig 4.)

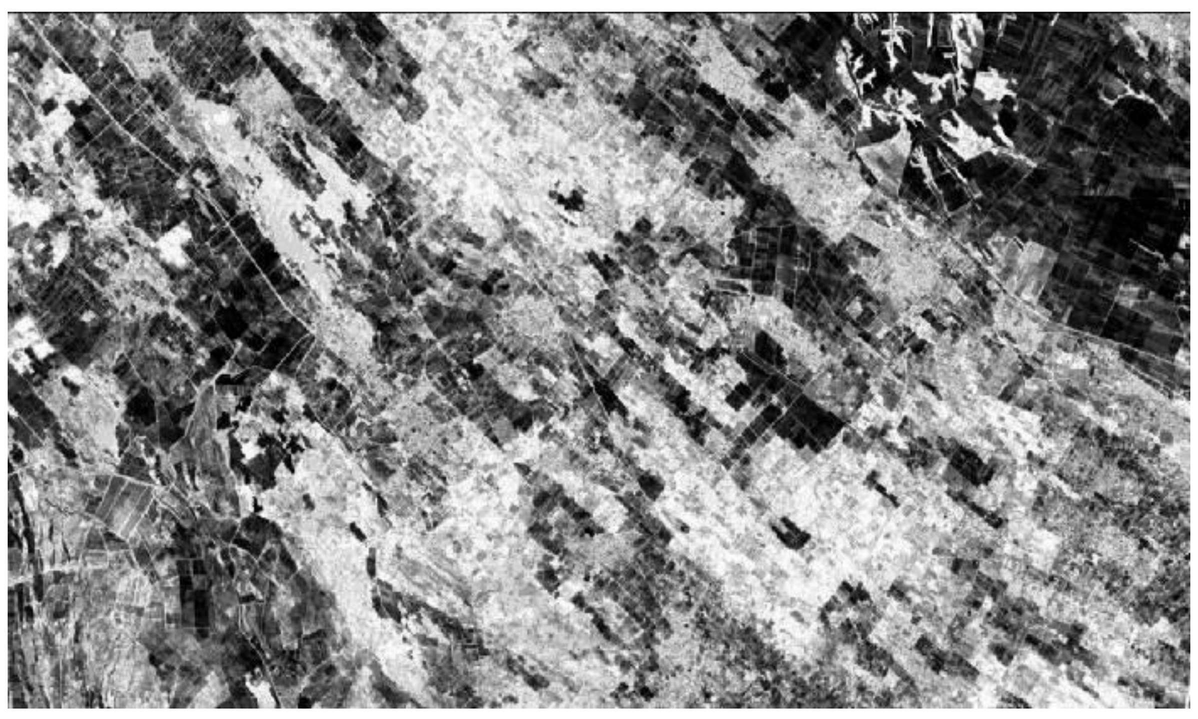


Fig. 4. Map of stability scores summarized over the period 1984-2016.
Bright colours indicate stable areas.

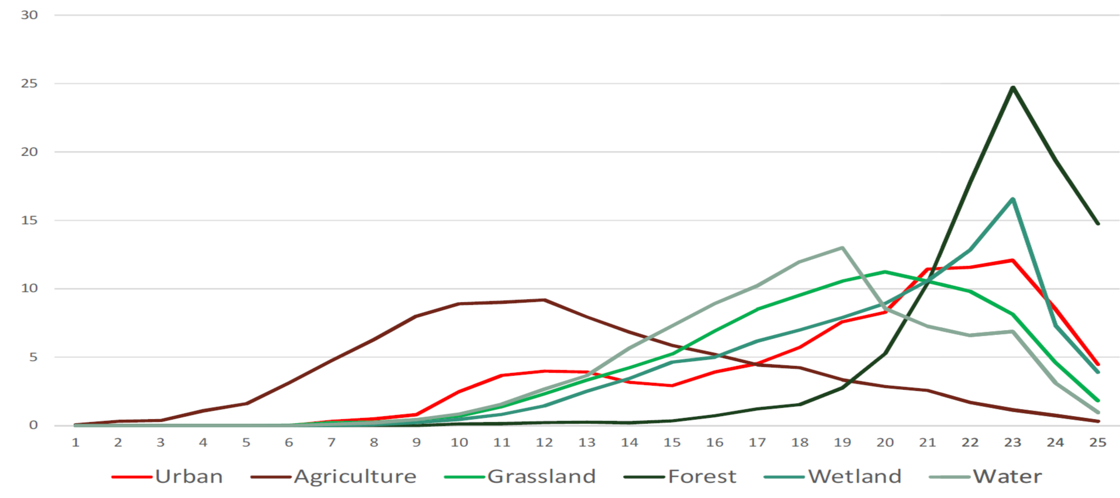


Fig. 5. Distribution of stability scores summarized over the period 1984-2016
Vertical axis: territory (%) against the total territory of the given category;
Horizontal axis: stability score

Based on the distribution of stability scores among land cover categories (Fig. 5), we observe the following:

- **most stable land surfaces are** situated within **forested areas**
- **agriculture is the least stable** category due to frequent spectral changes
- another interesting observation is the **bimodal distribution of urban areas**, probably due to urbanization trends.

C. Changes in spatial land use patterns assessed via high pass filtering

- **Averaging over the main distinct periods** (1984-1991, 1992-2000, 2001-2016) provided good overview of the importance and stability of landscape boundaries.
- A **composite visualization** combining results for the three periods enhances structural changes in a highly visible way (Fig. 6).

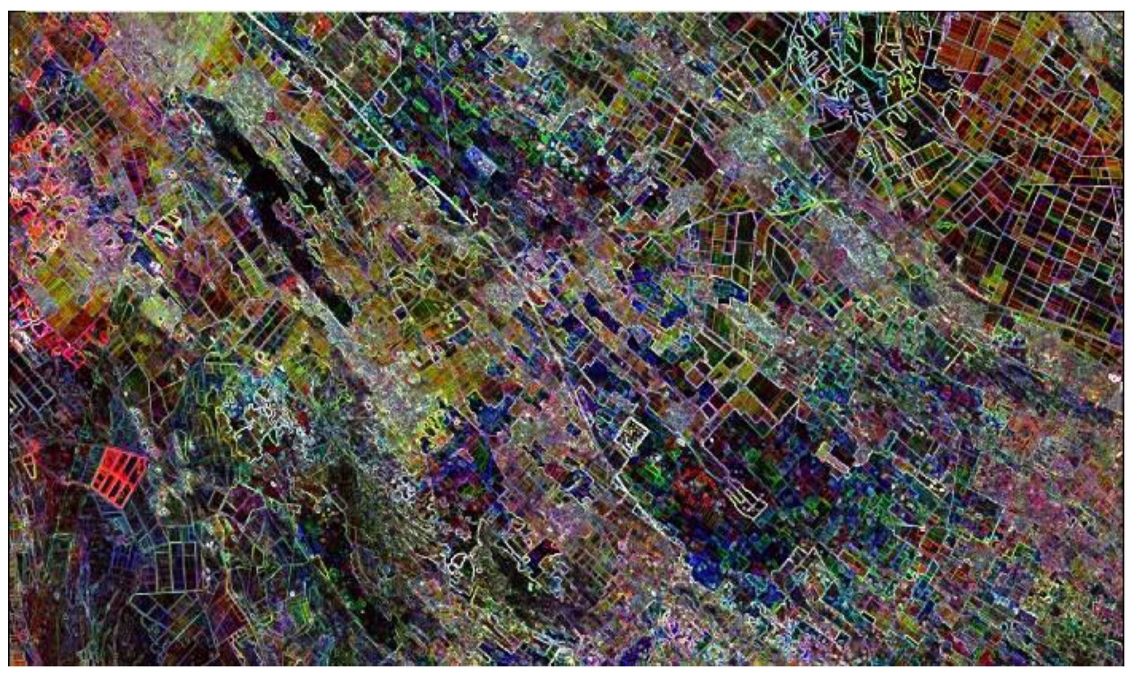


Fig. 6. Composite of HPF average values.
Represented periods: 2001-2016 (R); 1992-2000 (G); 1984-1991 (B).
White and gray colours: stable features (e.g. motorway, stable boundaries). Reddish colours: recently created boundaries (e.g. lakes). Green yellow colours: borders created between 1992 and 2000 (fragmentation of agricultural land). Blue colours: old boundaries do not exist anymore (mainly revegetated forest cuts).

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 LandsatLinkr
3. LandTrendr 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.

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