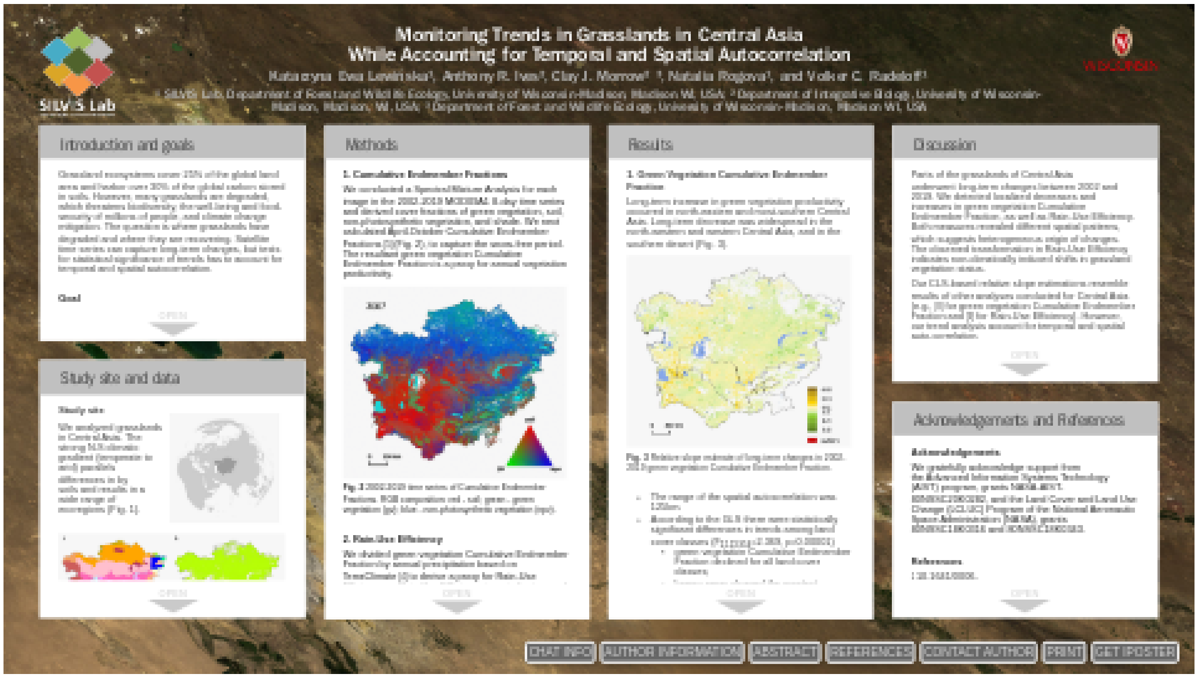
Monitoring Trends in Grasslands in Central Asia While Accounting for Temporal and Spatial Autocorrelation



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INTRODUCTION AND GOALS

Grassland ecosystems cover 25% of the global land area and harbor over 30% of the global carbon stored in soils. However, many grasslands are degraded, which threatens biodiversity, the well-being and food-security of millions of people, and climate change mitigation. The question is where grasslands have degraded and where they are recovering. Satellite time series can capture long-term changes, but tests for statistical significance of trends has to account for temporal and spatial autocorrelation.

Goal

To identify statistically significant long-term trends in grassland ecosystems in Central Asia:

- using a remote sensing approach suitable for sparse vegetation conditions;
- account for temporal and spatial autocorrelation in the data;
- test for significant differences of trends among land cover classes and ecoregions.

STUDY SITE AND DATA

Study site

We analyzed grasslands in Central Asia. The strong N-S climatic gradient (temperate to arid) parallels differences in by soils and results in a wide range of ecoregions (Fig. 1).

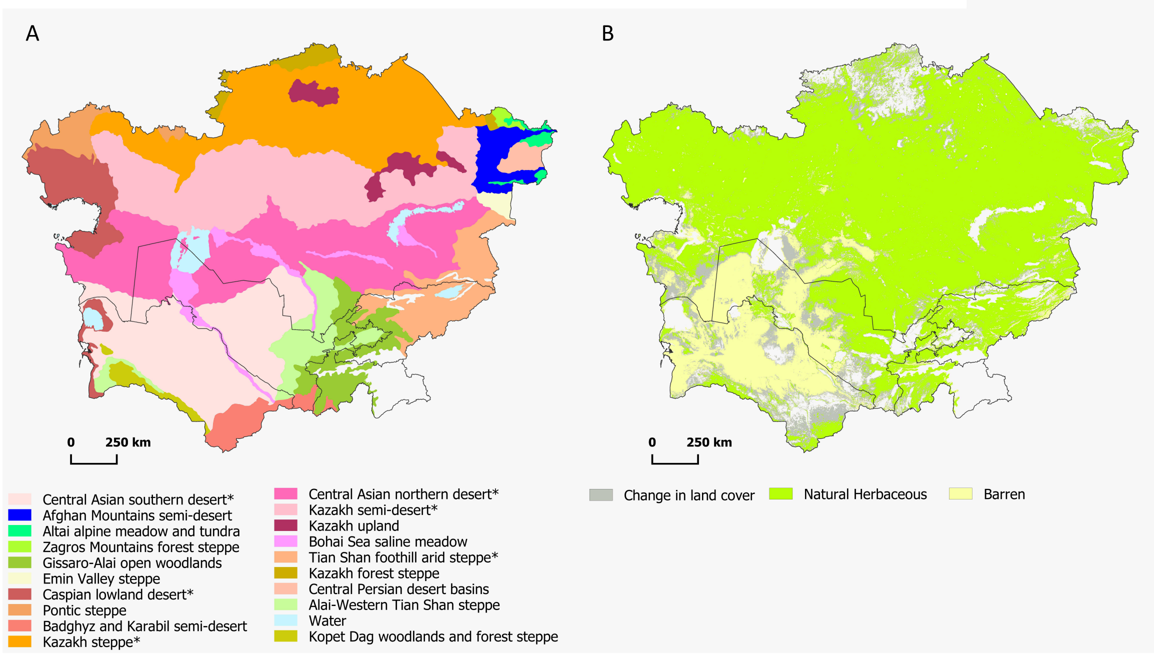

Fig.1 Central Asia: A) ecoregions (after Olson et al. 2001[1]) and B) land cover (after FAO LCCS2 [3]). Ecoregions marked with * were included in the trend analysis.

Data

We analyzed the following datasets:

- 2002-2019 MODIS MOD09A1 time series 8-day 500m surface spectral reflectance [2];
- 2002-2018 MODIS MCD12Q1 land cover data in FAO LCCS 2 classes [3];
- 2002-2019 precipitation from TerraClimate [4]
- Ecoregions of the World [1]

METHODS

1. Cumulative Endmember Fractions

We conducted a Spectral Mixture Analysis for each image in the 2002-2019 MOD09A1 8-day time series and derived cover fractions of green vegetation, soil, non-photosynthetic vegetation, and shade. We next calculated April-October Cumulative Endmember Fractions [5] (Fig. 2), to capture the snow-free period. The resultant green vegetation Cumulative Endmember Fraction is a proxy for annual vegetation productivity.

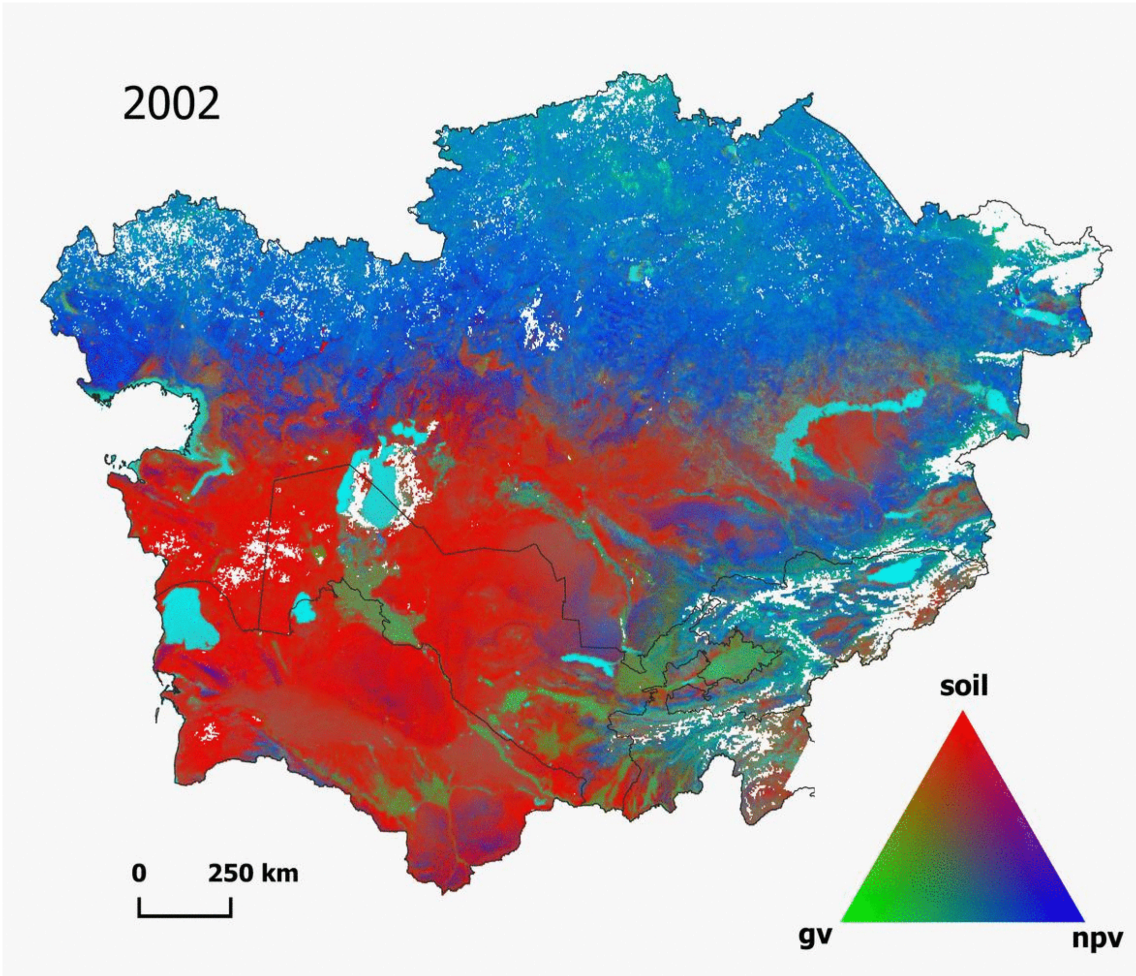

Fig. 2 2002-2019 time series of Cumulative Endmember Fractions. RGB composition: red - soil; green - green vegetation (gv); blue - non-photosynthetic vegetation (npv).

2. Rain-Use Efficiency

We divided green vegetation Cumulative Endmember Fraction by annual precipitation based on TerraClimate [4] to derive a proxy for Rain-Use Efficiency [6]. Rain-Use Efficiency is an indicator used to study ecosystem functioning through vegetation response to hydrological condition.

3. Trend Analysis

Our trend analysis comprises two steps [7]:

- pixel-level Conditional Least Squares (CLS) regression analysis which regresses $x_i(t)$ against t and $x_i(t-1)$ to obtain a slope estimate $c_{i,cls}$ of long-term change (where x is a value of interest in pixel i at time t);
- General Least-Square (GLS) regression on the slope estimates that includes spatial covariance, thereby accounting for spatial autocorrelation, and allows for additional explanatory variables.

For more details on our trend analysis approach see **this AGU poster by Anthony R. Ives (/Default.aspx?s=C1-BC-FD-F1-00-29-6F-DE-84-4B-C9-15-B9-DE-A9-37).**

We ran trend analyses for two time series:

- 2002-2019 green vegetation Cumulative Endmember Fraction;
- 2002-2019 Rain-Use Efficiency.

In the GLS we tested for differences in long trends among:

- three main land cover classes, namely stable herbaceous, stable barren, and transitional class (change between herbaceous and barren) (Fig. 1B);
- six main ecoregions (Fig. 1A).

RESULTS

1. Green Vegetation Cumulative Endmember Fraction

Long-term increase in green vegetation productivity occurred in north-eastern and most-southern Central Asia. Long-term decrease was widespread in the north-western and western Central Asia, and in the southern desert (Fig. 3).

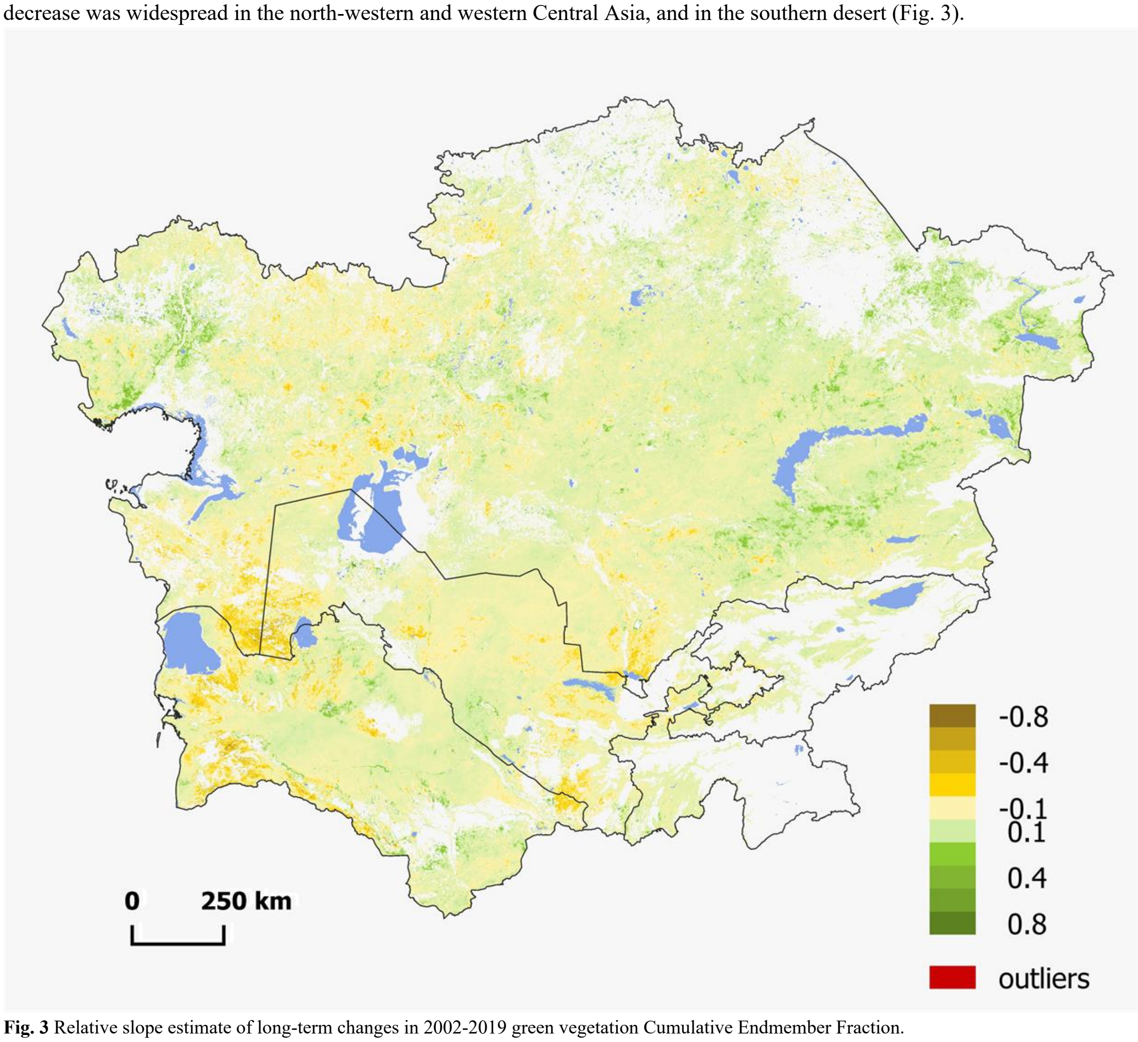

Fig. 3 Relative slope estimate of long-term changes in 2002-2019 green vegetation Cumulative Endmember Fraction.

- The range of the spatial autocorrelation was 125km.
- According to the GLS there were statistically significant differences in trends among land cover classes ($F_{2,123,954}$=2.369, p=0.00001)
  - green vegetation Cumulative Eedmember Fraction declined for all land cover classes;
  - barren areas showed the greatest decrease;
  - overall change in herbacious regions was negative but close to 0.
- Difference in trends among ecoregions was significant but weak ($F_{5,118,270}$=1.44, p=0.04)
  - the greatest increase in green vegetation Cumulative Eedmember Fraction took place in Caspian lowland desert;
  - Central Asia southern desert showed the strongest decline in green vegetation Cumulative Eedmember Fraction.

2. Rain-Use Efficiency

We observed an overall increase in Rain-Use Efficiency in Central Asia, with Rain-Use Efficiency reduction in the Kazakh Uplands and eastern part of Central Asia semi desert (Fig. 4).

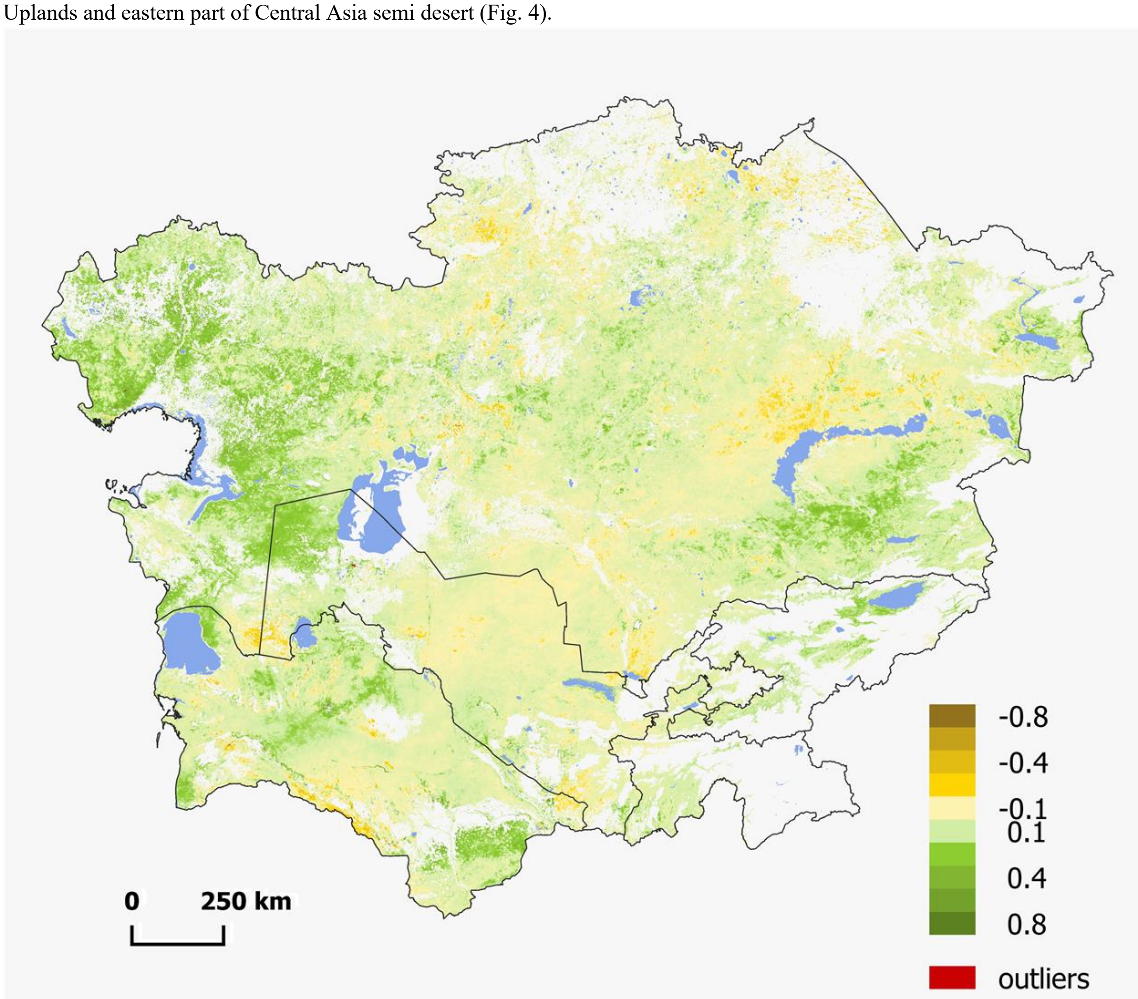

Fig. 4 Relative slope estimate of long-term changes in 2002-2019 Rain-Use Efficiency.

- Spatial autocorrelation in Rain-Use Efficiency was 305km;
- Long-term changes in Rain-Use Efficiency were statistically significant among land cover classes ($F_{2,124,062}$=6.615, p=0.00001)
  - all classes showed decline;
  - the strongest decline occured in barren regions.
- Differences in trends were insignificant among ecoregions ($F_{5,118,273}$=0.716, p=0.953).

DISCUSSION

Parts of the grasslands of Central Asia underwent long-term changes between 2002 and 2019. We detected localized decreases and increases in green vegetation Cumulative Endmember Fraction, as well as Rain-Use Efficiency. Both measures revealed different spatial patterns, which suggests heterogeneous origin of changes. The observed transformation in Rain-Use Efficiency indicates non-climatically induced shifts in grassland vegetation status.

Our CLS-based relative slope estimations resemble results of other analyses conducted for Central Asia (e.g., [8] for green vegetation Cumulative Endmember Fraction and [9] for Rain-Use Efficiency). However, our trend analysis account for temporal and spatial auto-correlation.

Spatial auto-correlation in the green vegetation Cumulative Eendmember Fraction time series was up to 125 km and up to 305 km in Rainfall-Use Efficiency. Spatial auto-correlation can inflate significance in statistical tests. Our approach addresses this issue and accounts on the expected clustering of false-positives (type I errors) that results in spurious spatial patterns.
The F-scores showed land cover is a significant explanatory variable when analyzing long-term change in grasslands in Central Asia.

The statistical method used in this study will soon be available as a package written in the programing language R.

ACKNOWLEDGEMENTS AND REFERENCES

Acknowledgements

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ABSTRACT

Grassland ecosystems cover one-fourth of the global land area and harbor over 30% of the global carbon stored in soils. However, grasslands are subjected to extensive and intensive land degradation, which threatens biodiversity, the well-being and food-security of millions of people, and poses challenges for climate change mitigation. The question is where grasslands have degraded and where long-term greening is taking place. Time series of satellite data can be used for trend analyses, but when testing for statistical significance, it is important to account for temporal and spatial autocorrelation. Here we present our new statistical method to analyze long-term trends in grasslands based on physically-based Cumulative Endmember Fractions (annual sums of monthly ground cover fractions). Our trend analysis incorporates two steps: first we apply an autoregressive time series to each pixel to obtain a slope estimate while accounting for temporal autocorrelation. Second, we apply a general least-square regression to the slope estimates, in which we incorporate spatial covariance structure, as well as explanatory variables. We tested our approach mapping long-term trends in grasslands in Central Asia using MODSI 2001-2019 time series, which we regressed against meteorological measurements. Our results showed long-term changes of both, positive (i.e., revegetation; e.g., east part of Central Asia) and negative trajectories (i.e., desiccation; e.g., north-west part of the Central Asia). Importantly, our method is scalable and transferable to other time series of satellite data and regions, and can be implemented in any computational environment, assuring accessibility and reproducibility.