Dual scale trend analysis to evaluate climatic and anthropogenic effects on the vegetated land surface in agricultural Russia

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A. Overview

Russia's population is projected to shrink by a staggering 29% by 2050. Differential dynamics among rural populations are correlated with ethnicity and constitute a key driver in the spatial disintegration of rural Russia. Currently, Russia is slowly transitioning into a country with an internal "archipelago" of islands of productive agriculture around cities set within a matrix of much less productive and abandoned croplands. This heterogeneous spatial pattern is mainly driven by depopulation of the least favorable parts of the countryside, where "least favorable" is some function of lower fertility of land, higher remoteness from urban markets, or both.

We present a dual scale trend analysis to characterize change in agricultural European Russia and Kazakhstan. We selected a global NASA MODIS product (MCD43C4 and MCD43A4) at a 0.05° (~5.6 km) and 500m spatial resolution and a 16-day temporal resolution from 2000 through 2008. We applied a refinement of the Seasonal Kendall trend method to Normalized Difference Vegetation Index (NDVI) image series at both scales. We only incorporated composites during the vegetative growing season which was delineated by start of season and end of season estimates based on analysis of Normalized Difference Infrared Index (NDII) data. Trend patterns revealed areas of increasing NDVI trend in Russia which was linked through the dual scale analysis with agricultural land cover change. The coarser scale analysis was relevant to atmospheric boundary layer processes, while the finer scale data revealed trends that were more relevant to human decision-making and regional economics. We evaluated the weather patterns and land surface phenologies for the areas with increasing NDVI over the past 9 years and compared the results with areas without change. This analysis improved our understanding of the spatio-temporal weather and phenological patterns related to agricultural changes.

B. Data Sources and Pre-processing

5.6km - MCD43C4:

- NASA MODIS Terra+Aqua Nadir BRDF-Adjusted Reflectance data,16-day temporal resolution. Data are delivered every 8-days with the composites based on the previous 16-days.
- Subset global data to Eastern Eurasia, including Central Asia.

500m - MCD43A4:

- NASA MODIS Terra+Aqua Nadir BRDF-Adjusted Reflectance data, 16-day temporal resolution, 10°×10° tiles. Tiles: h20-23, v2-4.

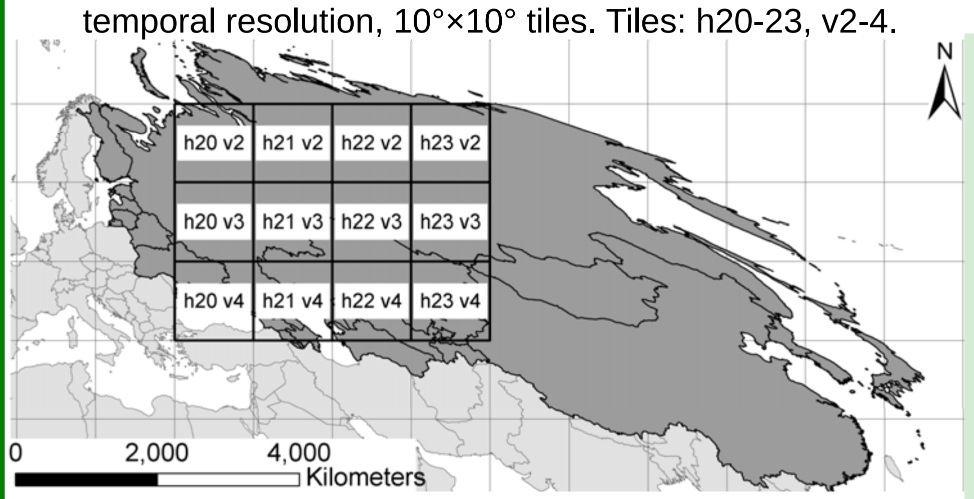


Figure 1: The study area with 0.05° resolution overlaps 20 countries in Eurasia and Central Asia and is shaded in dark grey. The study area selected for higher resolution analysis exists of 12 MODIS tiles, overlapping 69,120,000 pixels.

Pre-processing of MODIS time series:

- Calculate NDVI = (NIR-Red)/(NIR+Red) and NDII = (NIR-SWIR)/(NIR+SWIR) with NIR = b2, Red = b1, SWIR = b7.
- Composite the data into 16-day composites by calculating mean NDVI & NDII.
- Replace missing composites by composite period means.
- Mask pixels that: 1) lacked more than 20% of the data or 2) exhibited low NDVI seasonality identified as NDVI < 0.1 or CV NDVI < 5%. A total of 13.8% of the land surface was excluded.

Landsat Global Land Survey 2005:

- Russia: WRS – 2 Path 172 / Row 20. Capture date: August 16th, 2007.
- Kazakhstan: WRS – 2 Path 165 / Row 25. Capture date: August 27th, 2007.

Weather data:

- Station data from Russia's weather service (http://meteo.infospace.ru/) for one station for temperature (2000 – 2008) and precipitation (2000 – 2004).
- Station data from Kazakhstan (NCDC, 2008) for three stations for precipitation and temperature (2000-2006).
- Gridded monthly precipitation data from the Global Precipitation Climatology Center (GPCC) from 2000 – 2007.
- We found very high correspondence between the GPCC data and the precipitation station data in Russia ($r^2 = 0.95$)[1].

C. Methods

- Use the Seasonal Kendall trend (SK) test to determine trends for time series between the start and end of the growing season as determined based on NDII [2].

Seasonal Kendall Trend detection

- The original Mann-Kendall (MK) trend test is calculated by summing the number of times an observation has a higher value than any of the previous observations[3].
- The SK test: 1) Calculates the MK statistic for each composite separately and 2) Sums the MK statistics for all composites.
- The test statistic is asymptotically normal with a zero mean.
- The variance is defined as the sum of variances for every season plus the sum of the covariances for every combination of seasons.
- The covariance is corrected for autocorrelation between consecutive seasons[4,5] using Spearman's rank correlation coefficient for different seasons and years.

D. Results - Russia

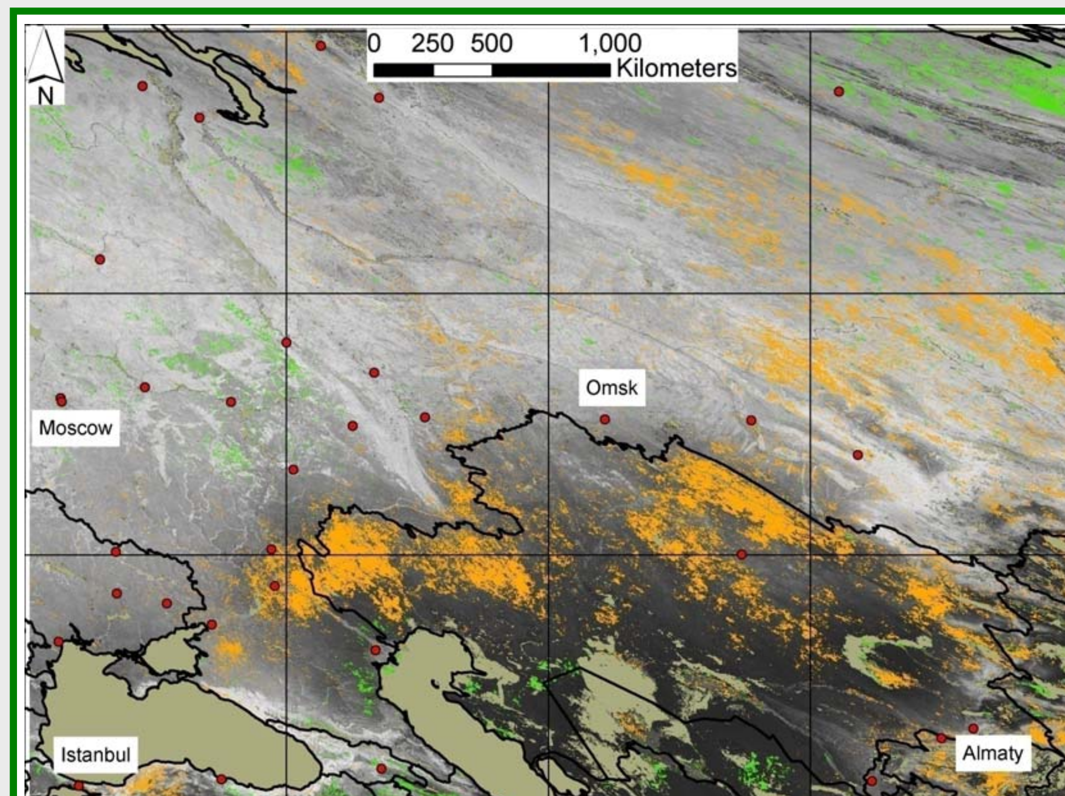


Figure 2: Vegetation trends from 2000 to 2008 revealed by NASA MODIS sensors at 500m spatial resolution. Areas outlined in orange and green indicate highly significant ($p \le 0.01$) negative and positive trends, respectively. Areas in tan were excluded from analysis. Areas in shades of grey did not exhibit highly significant trends. Overlaying grid box corresponds with the MODIS tiles.

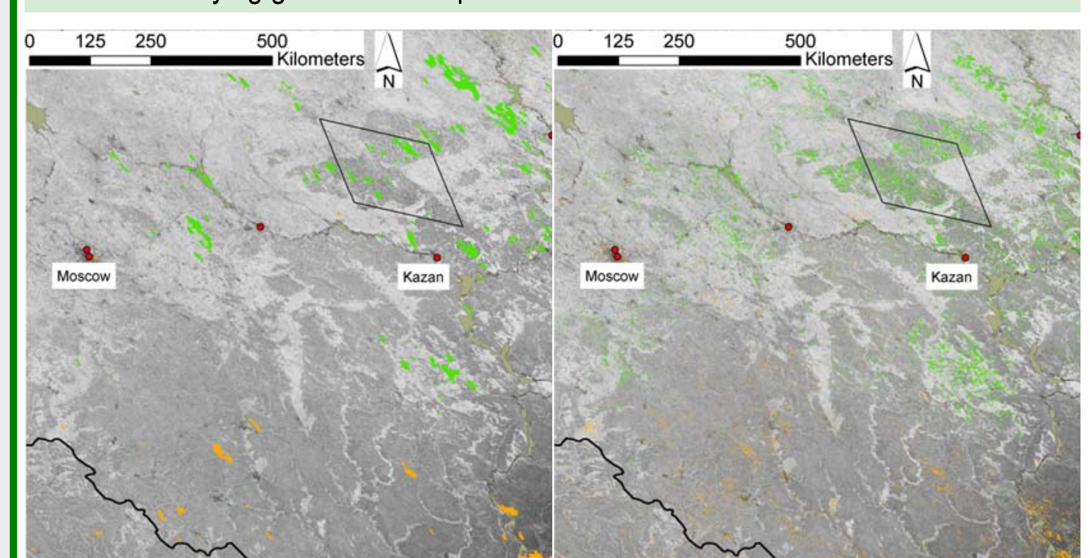


Figure 3: Close-up of the MODIS vegetation trends for tile h20v3 as observed at the 0.05° spatial resolution (**left**) and 500m resolution (**right**). The black box in the figure indicates the area selected for finer analysis.

- NDVI especially increased in croplands, suggesting an anthropogenic rather than a climatic cause.
- The selected study area is characterized by a depressed agricultural sector and emigration from rural to urban environment[6,7].
- The positive trend results from increased summer NDVI in the agricultural regions which is not found in the forested regions (Figure 4).
- We did not find significant trends in station temperature and GPCC precipitation[1].
- Results are different from previous research where we found that land abandonment in Kazakhstan, as a result of the collapse of the Soviet Union, was expressed as increased NDVI early in the growing season due to the succession of weeds, grasses and forbs that green up before annual crops are planted[8,9].

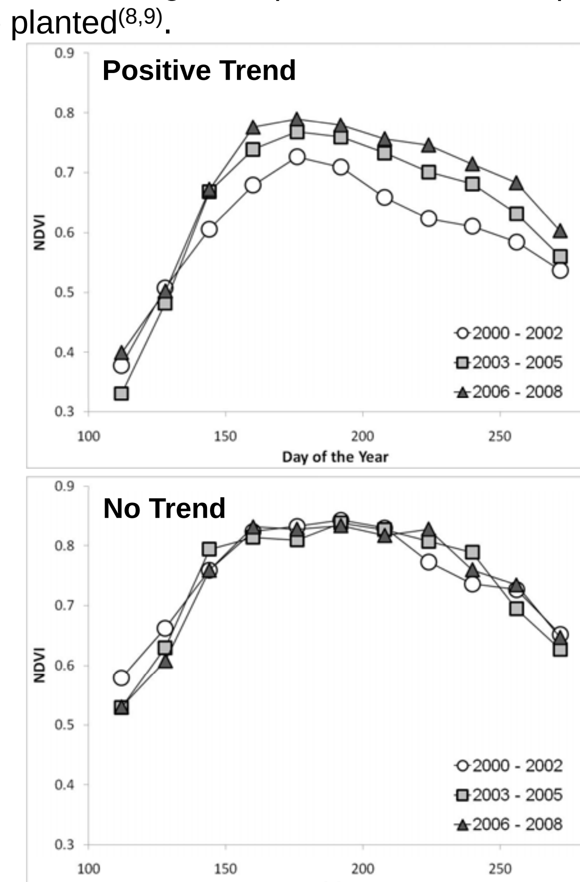


Figure 4 (**top**): NDVI in steps of three years based on the ten largest clusters with positive change within the black box in Figure 3 and (**bottom**) NDVI from an area without change. The agricultural regions reveal increased NDVI starting in the end of May (DOY 144). The adjacent forested regions do not reveal significant change.

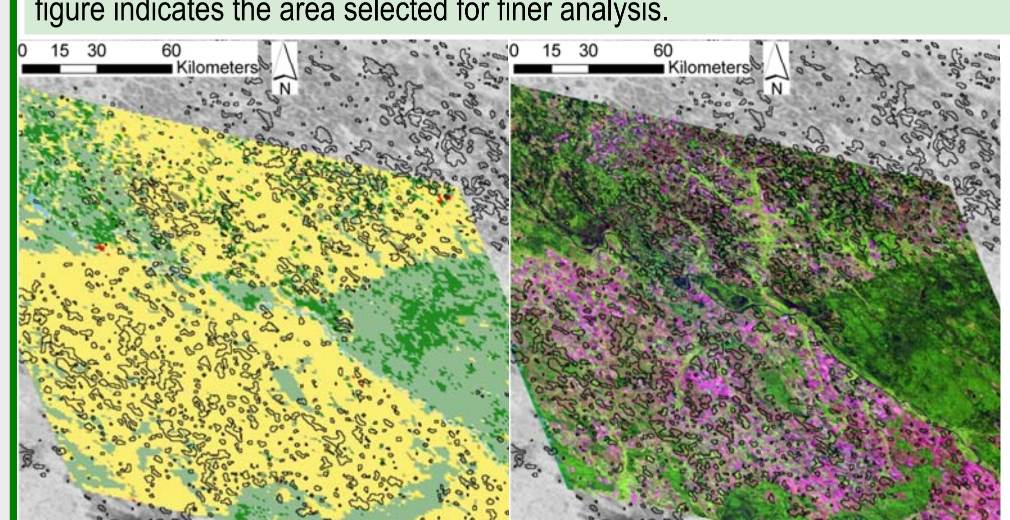


Figure 5 (**left**): MOD12 land cover data at 1km spatial resolution. Black outlines indicate positive trends found with the 500m NDVI trend analysis. Three main classes are evergreen needleleaf forests (dark green), mixed forests (light green) and croplands (yellow). (**right**) corresponding Landsat TM image displayed with bands 5,4,3 as r/g/b.

E. Results - Kazakhstan

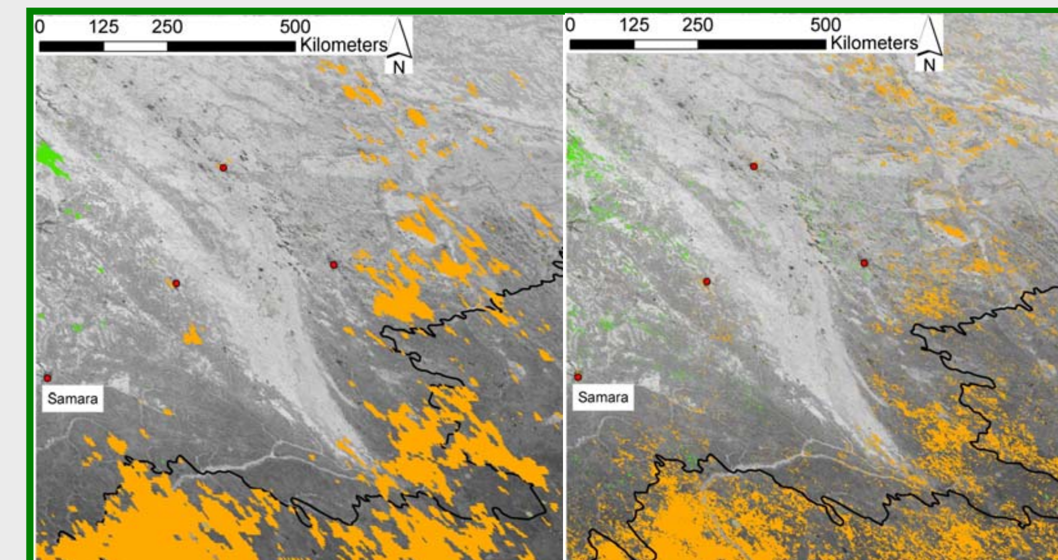
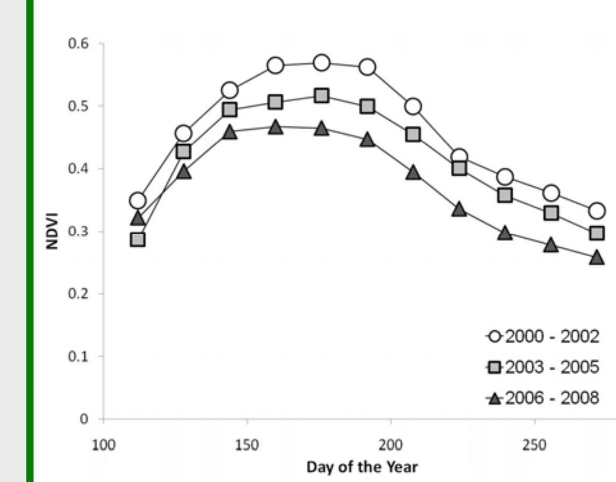


Figure 6: Close-up of the MODIS vegetation trends for tile h21v3 as observed at the 0.05° spatial resolution (**left**) and 500m resolution (**right**).



- The area of NDVI decline in the entire country is almost three times as large as the area with NDVI increases.
- The regions with negative trends are very widespread and span multiple land cover classes suggesting droughty condition.
- Drought was impacting the region especially in 2004[10]. FAO production statistics for Kazakhstan and negative precipitation trends[1, 11,12] confirm these conclusions.

Figure 7: NDVI in steps of three years based on the ten largest clusters with negative change. The NDVI curves are decreased relatively evenly across the growing season except for the first composite (DOY 122) which could be the result of some residual moisture available after snow melt. The decline in NDVI is largest during the peak of the growing season.

F. Conclusions

- The general pattern of trend is comparable for the two scales.
- Trends detected at coarser resolution may include areas that are not significant at the finer resolution due to the aggregation.
- Coarser scale trends are relevant to the atmospheric boundary layer processes.
- Finer scale analysis reveals trends that are more relevant to human decision-making and regional economics
- Even though the finer scale changes may disappear at the coarser resolution, it is not right to argue that these finer scale changes are not relevant.
- Rescaling of trend results is not straightforward due to 1) high spatial heterogeneity at finer scale, 2) the nonlinearity of vegetation indices, and 3) the thresholding effect of specific significance levels.
- Dual scale trend analysis enables a partitioning of change attribution that would be very difficult at a single scale.

G. References

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Acknowledgments:

This research was supported in part by the NEESPI and NASA LCLUC projects entitled ***Evaluating the effects of institutional changes on regional hydrometeorology: Assessing the vulnerability of the Eurasian semi-arid grain belt*** to GMH and ***Land Abandonment in Russia: Understanding Recent Trends and Assessing Future Vulnerability and Adaptation to Changing Climate and Population Dynamics*** to KMdB. We would like to thank P. de Beurs for the application development that allowed us to estimate the trend statistics efficiently.