Land Surface Phenology in Kazakhstan: Climatic Variability and Institutional Change

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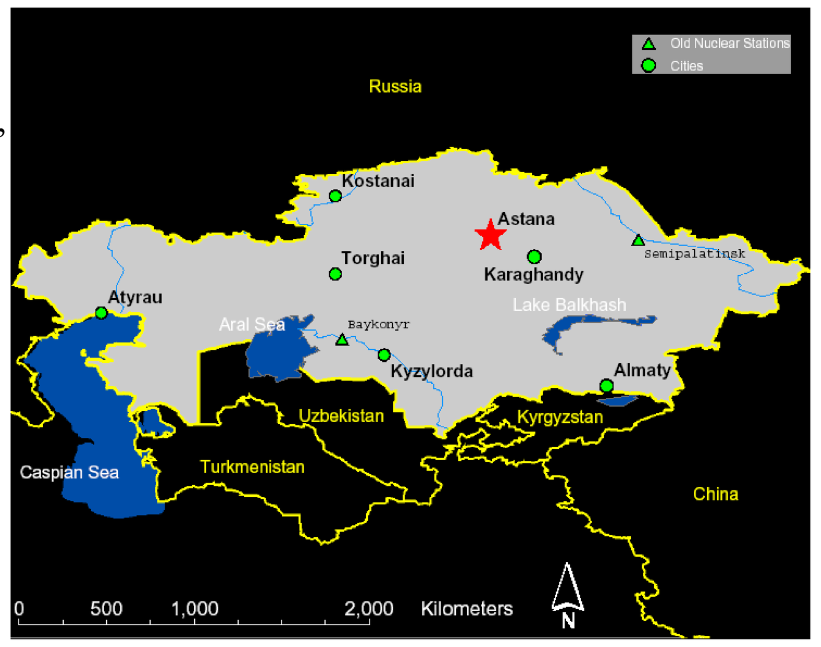
OVERVIEW

At 2.72 million km², Kazakhstan is more than one-third the size of the conterminous US or roughly equal in area to all of Western Europe, including the British Isles. It is bounded by China on the east, Kyrgyzstan and Uzbekistan on the south, the Caspian Sea and a small section of Turkmenistan in the west, and Russia in the north. Since the abrupt institutional changes surrounding the disintegration of the Soviet Union in the early 1990s, Kazakhstan has reportedly undergone extensive land-cover changes[1].

Few details are known, however, about the pace or extent of land cover change, due to the collapse of regional environmental monitoring networks in the early 1990s. Marked decreases in livestock and meat production accompany increases in productive rangelands, as measured by vegetation indices. Desocialization and associated privatization of agricultural production following institutional change are expected to increase agricultural output [2,3].



To be able to assess the significance of changes in vegetation indices, it is necessary to examine the observational record and to place this episode within the larger context of interannual climatic variability and landscape dynamics. We used a standard global dataset to characterize the expected and actual spatio-temporal dynamics of the vegetated land surface.

Data Source

- Pathfinder AVHRR Land (PAL) maximum Normalized Difference Vegetation Index (NDVI) 10-day (dekad) composites (***http://daac.gsfc.nasa.gov***)
- Daily minimum and maximum temperature data and precipitation rate data from the NCEP/NCAR CDAS/Reanalysis Project, daily measurements on a 2.5°×2.5° grid (***http://wesley.wwb.noaa.gov/ncep_data/***)
- Temporal extent of image time series: 7/81-12/99 (330 images)
- Spatial resolution of image time series: 8 km
- Seasonal subsets of the image time series: (1) from 4/85 to 9/89 and (2) from 4/95 to 9/99
- Spatial subsets selected near Kyzylorda: (1) irrigated rice area and (2) desert area.

Processing Methods

A: *Identification of agricultural subsets*

- From the image time series a five-year periods were selected before and after institutional change: 1985-1989 and 1995-1999.
- The first two dekads of April images were excluded from the selection due to high interannual variation in extent of snow cover.
- Two subsets (576 km²) were selected near Kyzylorda in southern Kazakhstan. Areas were chosen due to the arid environment, desert land cover, and the extensive irrigated agriculture around the Syr-Darya river.

B: *Time series analysis*

- The sampling distributions were summarized using simple descriptive statistics: mean, median, coefficient of variation.
- The irrigated area time series was assessed for trends and compared with trends from the time series of the desert area, to control for artifacts due to changes in satellites.

C: *Growing Degree Day models*

- A second-order polynomial model of the NDVI against the growing degree-days (GDD) was fit for the irrigated area time series for each time periods
- The performance of the models was compared with r², adjusted r², and the coefficient of variation (CV %) of the model.
- The model parameters were tested for similarity using Student's t-test.

D: *Principal Component Assessment*

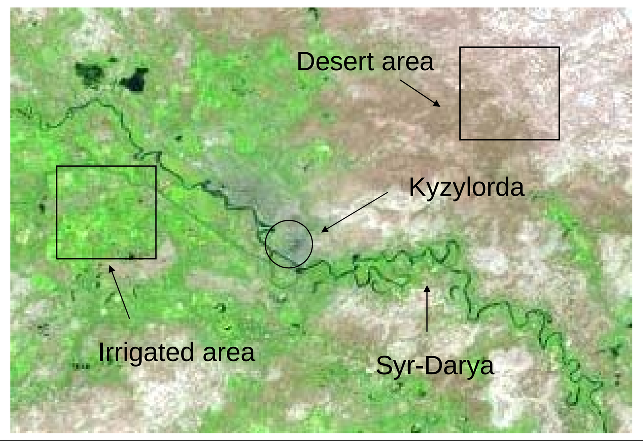
- Principal components were developed for total dataset and assessed for trends. Dominant components were plotted and compared.

A: Identification of agricultural subsets

Two areas are chosen near the city of Kyzylorda (44° 51' 10" N 65° 30' 33" E)

1. an irrigated rice area; located next to the Syr-Darya river in the middle of the desert.
2. a desert area which is used to test for deviations and trend due to satellite artifacts.

The areas are less then 100 km from each other, and since the measurement grid of NCEP data is much coarser, the areas are assumed to have a similar climate regime.
There is assumed that temperature is the only limiting crop growth factor.



B: Time series analysis

Wilcoxon's test:
Average NDVI in the irrigated area is significantly higher after constitutional change than before ($p<0.05$).
Average NDVI in the desert area is significantly lower in the second time period.

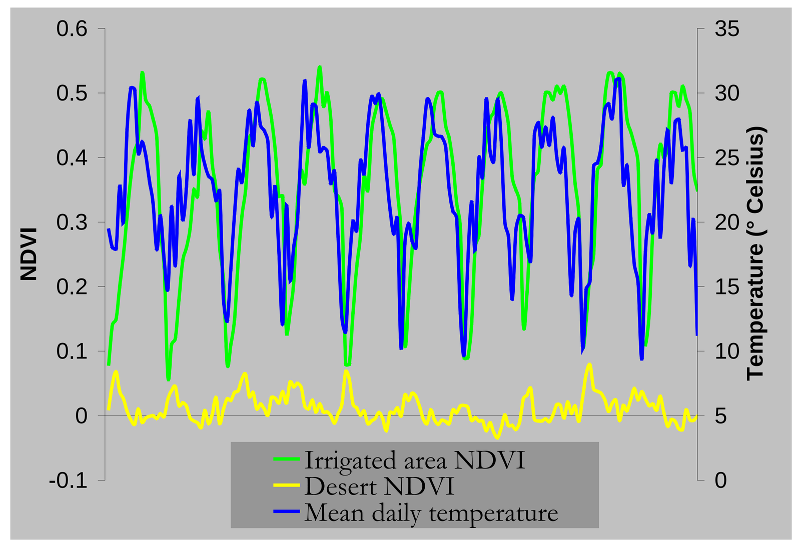
(**Upper image**) NDVI from the irrigated area and the desert and temperature.
The NDVI in the irrigated area tracks the temperature regime closely.
The NDVI in the desert does not track the temperature regime.
The NDVI values in the desert are much lower.

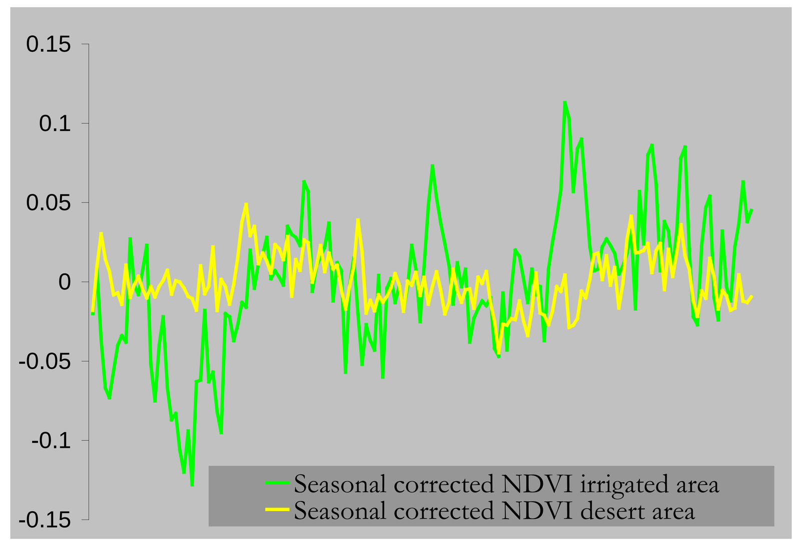
(**Lower image**) NDVI residuals after seasonal correction.

There is no trend in the desert NDVI over time.

NDVI in the irrigated areas shows an upwards trend; this trend area can not be due to satellite artifacts because a comparable trend is not visible in the desert.

Temperature data exhibit no significant trend between time periods (not shown).





C: Growing Degree Day models

Simple linear regression has been applied with the NDVI as response variable and GDD as explaining factor.

The models show a very good fit (see table below).

- The first time period shows more interannual variation in NDVI. This results in a poorer model fit for this period.
- Student's t-test was used to test for significant differences between model parameters as follows:

1. (a) quadratic parameters were tested and found to be not significantly different; (b) these parameters were averaged and the new quadratic parameter was used in revised models;

2. (a) linear parameters of the revised models were tested and found to be not significantly different; (b) these parameters were averaged and the new linear parameter was used in re-revised models;

3. intercepts of the re-revised models were tested and the ***intercept for the second time period was found to be significantly higher ($p<0.001$)***

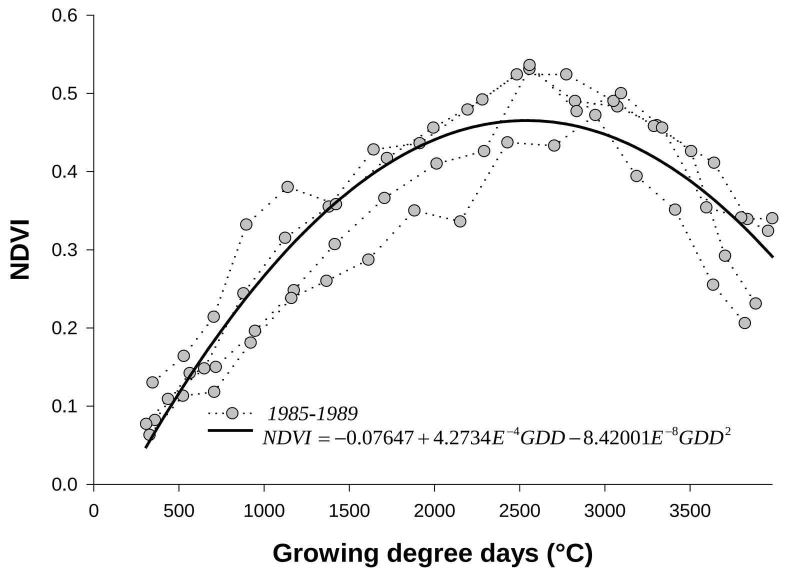
- The final models are:

$NDVI = -0.07717 + 4.282E^{-4}GDD - 8.439E^{-8}GDD^2$ ***(1985-1989)***

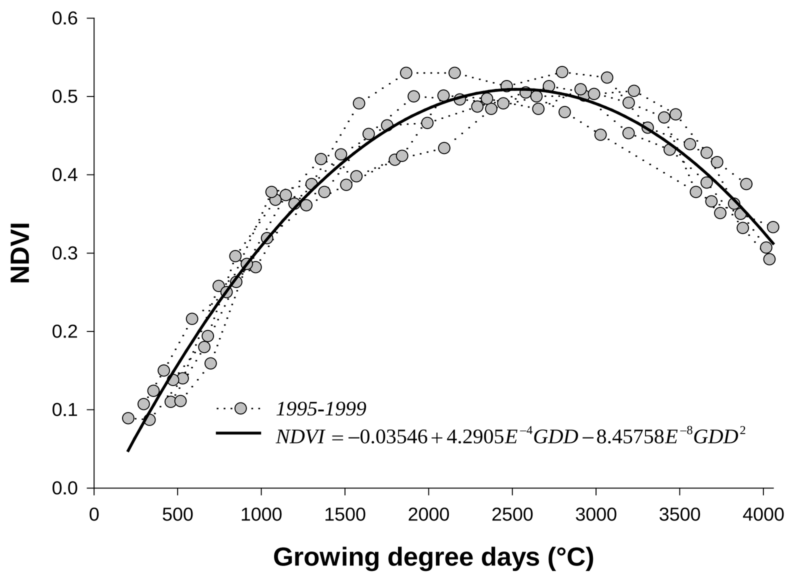
$NDVI = -0.03476 + 4.282E^{-4}GDD - 8.439E^{-8}GDD^2$ ***(1995-1999)***

NDVI is explained by growing degree days in a similar way for both time periods; however, after the institutional change NDVI is higher. Furthermore, there is less interannual variation in NDVI during the second time period.

	r^2	r^2 adj	RMSE (NDVI)	C.V. (%)
1985-1989 (original)	0.8731	0.8701	0.048	14.503
1995-1999 (original)	0.9511	0.9499	0.029	7.603
1985-1989 (final)	0.8734	0.8734	0.048	14.318
1995-1999 (final)	0.9511	0.9511	0.028	7.506



NDVI-Growing degree days original model (1985-1989)



NDVI-Growing degree days original model (1995-1999)

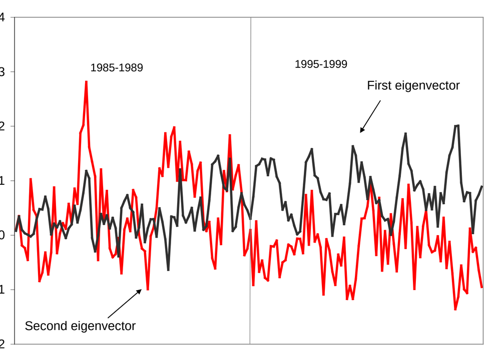
D: Principal Component Assessment

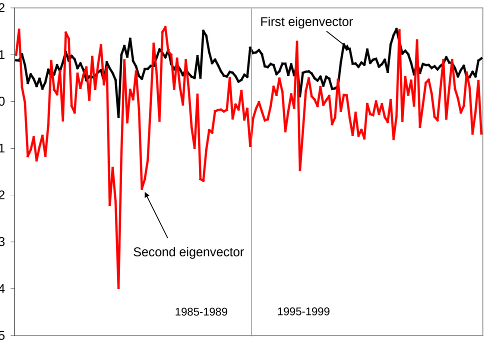
Principal components are developed for both areas.
First 8 eigenvectors explain >99% of the variation.
PC1 and PC2, explaining 89% of the variation, are shown here. PC1 captures the seasonal pattern.
The irrigated area shows a more regular pattern after institutional change.

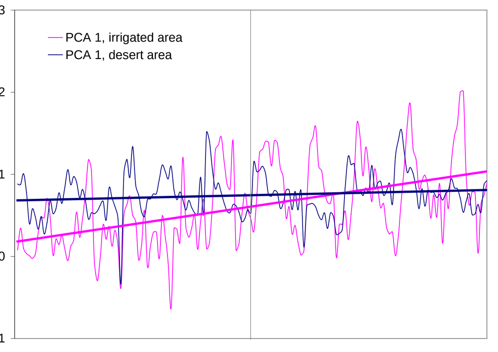
Middle image shows PC1 and PC2 for the desert area.
Desert PC1 shows less seasonality than irrigated PC1.

Lower image shows PC1 for the irrigated and the desert area. There is a positive trend evident in PC1 of the irrigated area. This trend is shown as a linear regression line for the measurement. The desert shows no increase. Since we do not find a trend in the desert, we conclude that the positive trend of PC1 in the irrigated area is not an artifact due to changes in satellites between or within the periods.

(**Top**) PC1 and PC2 for the irrigated area over the whole year, the grey line halfway the graph splits the data in two periods. (**Middle**) Desert PC1 and PC2. (**Lower**) PC1 for the irrigated area shows a positive trend that is not evident in PC1 of the desert.







Conclusions

We have shown four ways (Wilcoxon, seasonal-corrected time series, bioclimatological model, PCA) to analyze NDVI time series data and assess for significant differences among areas or time periods.

- We performed simple statistic tests to investigate trends. Seasonal-corrected time series show a positive trend in the irrigated NDVI while this trend is not evident in the desert area. Non-parametric statistics show higher mean NDVI values after institutional change than before. NDVI values in desert are lower after institutional change.
- NDVI has been modeled with the growing degree days as the independent variable. This bioclimatological model performs well for both periods. Relevant econometric research of socialized agriculture has shown:

  (1) interannual variation of crop production under centralized planning can be significantly greater than under private ownership and market economies[2]; and

  (2) the variability of efficiencies on state farms are significantly greater than in private farms, although the average efficiencies of state and private farms are similar[3].

  In our model only the intercept parameters are significantly different. The y-intercept is larger following institutional change and, as the other model parameters are equal, NDVI is larger. The better fit of the model to the data in the second time period indicates lower interannual variation following institutional change. In related results for the northern wheat belt, we have found that there has been an increase in expression of NDVI seasonality, which may be related to increased fallow area and decreased livestock grazing.[4]
- PCA shows clear seasonality in PC1 following institutional change. Prior to the change, more variation in NDVI is evident. In a related study[5] we found that the spatial dependence structure of NDVI in southern Kazakhstan was significantly less variable following institutional change, which supports our findings here.

References

[1] Esekin, B.K., et al. 2000. Kazakhstan, State of the Environment. *National Environmental Center for Sustainable Development of the Republic of Kazakhstan*. www.grida.no/enrin/htmls/kazahst/soe2/

[2] Brada, J. C. 1986. The variability of crop production in private and socialized agriculture: evidence from Eastern Europe. *Journal of Political Economy* 94:545-563.

[3] Brada, J.C., and A.E. King. 1993. Is private farming more efficient than socialized agriculture? *Economica* 60:41-56.

[4] Suleimenov, M., and P. Oram. 2000. Trends in feed livestock production, and rangelands during the transition period in three Central Asian countries. *Food Policy* 25:681-700.

[5] Henebry, G.M., K.M. de Beurs, and A.A. Gitelson. 2002. Land surface dynamics in Kazakhstan: dynamic baselines and change detection. *Digest of IGARSS 2002*, IEEE, Piscataway NJ. II:1060-1062.

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Land Cover Land Use Change

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