Evaluating the effects of institutional change on regional hydrometeorology: Assessing the vulnerability of the Eurasian semi-arid grain belt

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A. Overview

The 20th century witnessed some of the most extensive and abrupt land cover / land use changes (LCLUC) in human history. In the mid-1950s, Khrushchev's Virgin Lands Program rapidly expanded the intensive cultivation of grains across the Eurasian steppes. The collapse of the Soviet Union in the early 1990s is now recognized as another widespread LCLUC event [1,2].

The principal mechanism of LCLUC across this region was the disintegration of the institutions of centralized control over the agricultural sector. Without these controls and subsidies the agricultural sector contracted sharply during the 1990s throughout the Former Soviet Union and its client states.

There were significant consequent changes in biogeophysical processes, including the onset and timing of land surface phenology (LSP) that links the ecological dynamics of the vegetated surface with the atmospheric dynamics of the boundary layer.

- **Have the changes in land surface phenology affected the regional hydrometeorology?**
- **What has happened to the regional hydrometeorology in the wake of fundamental institutional changes?**
- **What are the "alternative presents" and future scenarios, given the current state and trends of the land surface and the atmosphere?**

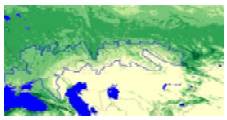
This interdisciplinary collaborative discovery-driven NASA NEWS proposal combines retrospective change analysis of meteorological and remotely-sensed data with simulation modeling using a proven regional scale numerical weather prediction model (MM5) coupled to a land surface model (NOAH).

We will explore "alternative presents" by changing LSP while using forcings from NCAR Reanalyses and we will explore possible futures by using forcings from selected GCMs.

Analyses of the retrospective data and the proposed suites of simulations should be able to address which conditions lead to enhancement of vulnerability versus enhancement of resilience in this semi-arid region.

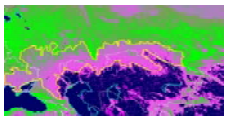
B. Study Region: Selection & Characteristics

- The semi-arid grain belt of Eurasia covers about 200 million hectares and extends from eastern Ukraine across southern Russia and northern Kazakhstan and from the Irano-Turanian deserts to the foothills of the Tian-Shan and the Altai Mountains.
- The current population in the region is roughly 41 million with 70% in eastern Ukraine.
- There are three grain crops grown within the region: barley, winter wheat, and spring wheat.
- Cropping predominantly follows a rain-fed fallow rotational system.
- We have delineated the study region using the Pathfinder AVHRR Land (PAL) NDVI data.
- The semi-arid grain belt emerges clearly from these data using a filter that is similar to a long time exposure, *riz*, pixel-wise counts of compositing periods in which NDVI>0.

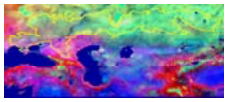


PAL **NDVI** average for 1982-1999. This is a semi-arid ecotonal – poised between forest and desert – and thus is especially sensitive to anthropogenic desertification and global climate change. Resolution = 8 km.

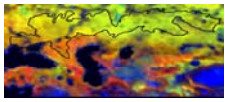
0.3 0.4 0.5 0.6 0.7



PAL **NDVI** for 1982-99 with binary threshold filter selecting pixels with NDVI> 0.5. Image time series summary shows coefficient of variation of counts as red, sum of counts as green, and skewness of counts as blue. Resolution=8 km.



AMSR-E **soil moisture product** for afternoon acquisitions (ascending orbits) in 2003. Image time series summary shows mean as red, standard deviation as green, and skewness as blue. Spatial resolution=25 km.



AMSR-E **vegetation water content** product for afternoon acquisitions (ascending orbits) in 2003. Image time series summary shows mean as red, standard deviation as green, and skewness as blue. Spatial resolution=25 km

C. Research Objectives

Hypothesis 1: The land cover and land use changes following the collapse of the Soviet Union were sufficiently *extensive* to affect the hydrometeorology of the semi-arid grain belt of Eurasia, inducing significant changes in energy and moisture exchange between land surface and atmosphere, thereby modifying regional patterns of precipitation and surface conditions.

- In our prior work we modeled NDVI as a function of accumulated GDD (AGDD base 0 °C).
- LSPs of agricultural areas fit well a quadratic model.
- We have previously established that there have been changes in LSPs at scales likely to influence boundary layer atmospheric dynamics [2,3,4].
- Here we will address directly two related questions:

  Q1. Can the LSP changes of these types, magnitudes, and extents *influence* the regional hydrometeorology as seen in changes to the precipitation regime?

  Q2. Have these LSP changes *already influenced* the regional hydrometeorology?

Hypothesis 2: The changes in regional hydrometeorology have made the Eurasian semi-arid grain belt more vulnerable to drier conditions under the influence of climate modes and this vulnerability will be enhanced given current GCM and RCM predictions under the 1990 "Business as Usual" scenarios [5,6].

- Climatic variation attributable to climate modes needs to be distinguished from directional climate change that can be attributed to anthropogenic activities [7].
- It is important to establish how climatic forcings affect land surface dynamics in order to assess the vulnerability of ecosystems in semi-arid environments.
- Literature shows that various teleconnections can affect meteorological variables within the study region [8,9].
- A characterization of teleconnection influences on LSP has thus far not been conducted.
- Synergistic use of ground observations of meteorological conditions and satellite observations of land surface phenology is necessary to evaluate the influence of climate modes.
- To address the question of vulnerability we must answer two sets of questions:

  Q3. To what extent are the harsher growing seasons observed within the historical weather record associated with climate modes? To what extent can these associations be observed in the satellite record? What is the effect of the teleconnections on LSP?

  Q4. What is the sensitivity of LSP in MM5-LSM in simulations forced by atmospheric conditions representing strong teleconnection influence?

D. Tasks

TASK A: Q1 *Modeling Studies* to Address H1
- MM5-LSM will be run over the study region using historic, contemporary, and altered land surface covers during the spring green-up phase for pre-collapse (1985-88) and two post-collapse periods (1995-1999 and 2002-2005).

TASK B: Q2 *Retrospective Analyses* to Address H1
- Retrospective analyses of multiple kinds of observational data: temperature and precipitation from ground stations, SSM/I, AMSR-E, AVHRR and MODIS time series, variables from retrospective modeling studies and the new higher resolution MM5-LSM simulations of TASK A.

TASK C: Q3 *Retrospective Analyses* to Address H2
- We will consider: NAO, Indian Ocean Dipole (IOD), Quasi-Biennial Oscillation (QBO), the lesser Eurasian modes, and the regional teleconnections identified by [10].

TASK D: Q4 *Model Sensitivity Analyses* to Address H2
- We will select particular growing seasons, force MM5-LSM with the associated atmospheric conditions, and observe the effects on hydrometeorological parameters in the context of the variations in the climate modes.

TASK E: *Vulnerability Analyses* to Address H2
- We will develop scenarios of human vulnerability to climate change that will embrace both:
  climate trends: projected by the selected GCMs and RCMs
  nonclimatic scenarios: due to socioeconomic, technological, land use & environmental changes

E. Expected Outcomes & Significance

We expect to address three broad outcomes:

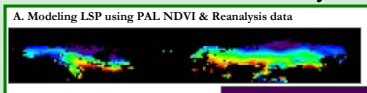
(1) Establish whether abrupt but far-reaching institutional change has already affected regional hydrometeorology via changes in land surface phenology and probe the sensitivity of this linkage.

(2) Establish how the link between land cover/land use and regional hydrometeorology is mediated in a semi-arid ecoregion by anthropogenic activities. The proposed analyses of the simulation suites should be able to address which conditions lead to *enhancement of vulnerability* (greater risk of desertification) versus *enhancement of resilience* (reduced risk of drought)

(3) Our synthesis of retrospective analyses of observational and modeling data will provide an important framework for application of vulnerability analysis to other semi-arid regions, particularly the integration of remote sensing datastreams into change analyses.

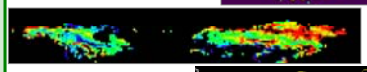
F. Preliminary Results

A. Modeling LSP using PAL NDVI & Reanalysis data



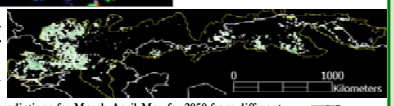
←1st PC of quantity of AGDD to peak NDVI in PAL data 1985-88 & 95-99.

1st PC of NDVI at start of seasonal observations in PAL data 1985-88 & 95-99. →

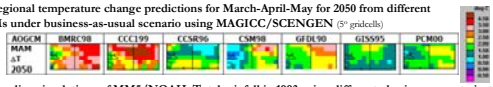


← 1st PC of seasonal dynamic range of NDVI in PAL data 1985-88 & 95-99.

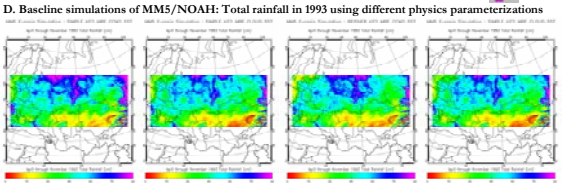
B. Seasonal Mann-Kendall test for trends using GIMMS 1982-2001 →
(excluding 1994). Green pixels are significant increasing trends at p<0.05; yellow shows study region; white shows national boundaries.



C. Regional temperature change predictions for March-April-May for 2050 from different GCMs under business-as-usual scenario using MAGICC/SCENGEN (5° gridcells)



D. Baseline simulations of MM5/NOAH: Total rainfall in 1993 using different physics parameterizations



G. Project Details

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Post-Doctoral Associate: Dr. Kirsten de Beurs
Graduate Students: one each at SDSU, SDSMT, and GVSU

H. References

[1] Hölzel, N., Haub, C., Ingelfinger, M.P., Otte, A., and Pilipenko, V.N. 2002. The return of the steppe large-scale restoration of degraded land in southern Russia during the post-Soviet era. Journal for Nature Conservation. 10(2):75-85.

[2] de Beurs, K.M., and G.M. Henebry. 2004a. Land surface phenology, climatic variation, and institutional change: Analyzing agricultural land cover change in Kazakhstan. *Remote Sensing of Environment* 89:497-509; doi:10.1016/j.rse.2003.11.006

[3] de Beurs, K.M., and G.M. Henebry. 2005. A statistical framework for the analysis of long image time series. *International Journal of Remote Sensing*, 26(8): 1551-1573.

[4] de Beurs, K.M., and G.M. Henebry. 2005. Land surface phenology and temperature variation in the IGBP high-latitude transects. *Global Change Biology*, 11, 779–790 .

[5] Lioubimtseva, E. 2004. Climate change in arid environments: revisiting the past to understand the future. *Progress in Physical Geography*, 28(4):502-530.

[6] Lioubimtseva, E., R.Cole, J.M. Adams and G. Kapustin, 2005. Impacts of Climate and Land-Cover Changes in Arid Lands of Central Asia. *Journal of Arid Environments*, 62(2): 285-308.

[7] Wang, G., and D. Schimel. 2003. Climate change, climate modes, and climate impacts. *Annu. Rev. Environ. Resourc.* 28:1-28.

[8] Dorn, W., Dethloff, E.K., Rinke, E.A., and Roeckner, E.E. 2003. Competition of NAO regime changes and increasing greenhouse gases and aerosols with respect to Arctic climate projections. *Climate Dynamics* 21:447-458.

[9] Ye, H. 2001. Characteristics of winter precipitation variation over northern central Eurasia and their connections to sea surface temperatures over the Atlantic and Pacific oceans. *Journal of Climate* 14:3140-3155.

[10] Ye, H. 2002. Observed regional and climatological associations between spring and summer precipitation over northern central Eurasia. *Water Resources Research* 38(12):1317.

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