Second Progress Report (2016-2017) for NASA LCLUC Project:

How Environmental Change in Central Asian Highlands Impacts High Elevation Communities [NNX15AP81G]

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PI: Geoffrey M. Henebry PhD

Geospatial Sciences Center of Excellence (GSCE)
South Dakota State University
1021 Medary Ave., Wecota Hall 506B
Brookings, SD 57007-3510
Email: geoffrey.henebry@sdstate.edu
Office: +1-605-688-5351 (-5227 fax)

Project Team
Geoffrey M. Henebry¹, PI
Guangqing Chi², Co-I
Pavel Ya. Groisman³, Co-I
Kamilya Kelgenbaeva¹⁵, Post-Doctoral Fellow
Monika Tomaszewska¹, Ph.D. student
Susannah Kane¹, Undergraduate Research Assistant
Ali Ibrahim¹, Undergraduate Center Scholar
Dean B. Gesch⁴, Collaborator
Jeffrey J. Danielson⁴, Collaborator
A.A. Aidaraliev⁵, Collaborator
Gulzhamal Ibraimova⁶, Collaborator
Gulchekhra Khasankhanova⁷, Collaborator
Alim S. Pulatov⁸, Collaborator

¹ South Dakota State University
² Department of Agricultural Economics, Sociology, and Education, Pennsylvania State University
³ Hydrology Science & Services Corporation
⁴ Earth Resources Observation and Science Center (EROS), U.S. Geological Survey
⁵ International University of Kyrgyzstan
⁶ Research Institute of Mountain Physiology, National Academy of Science of the Kyrgyz Republic
⁷ Design and Research Institute for Water Resources and Melioration (UzGIP), Ministry of Agriculture and Water Resources of Uzbekistan
⁸ EcoGIS Center, Tashkent Institute of Irrigation and Melioration (TIIM), Uzbekistan
A. Project Timeline 7/2015-8/2017

2015

07/05  Formal start of project funding

10/02-03  PI Henebry visits Bishkek, KG for initial meeting with IUK

12/01  PDF Kelgenbaeva arrives at SDSU

2016


04/14-16  Meetings with Kyrgyz and Uzbek collaborators about research project tasks, data requirements, and preparations for field activities.

05/27  First Progress Report submitted.

07/5-23  Field campaign in Naryn and At-Bashy rayons. Meetings with collaborators at the International University of Kyrgyzstan.

07/21  Exploratory meetings in Bishkek with researchers at the Mountain Societies Research Institute at the University of Central Asia, the Kyrgyz State University of Construction, Transportation, and Architecture, and the Institute of Physical & Technical Problems and Materials Science of academician J. Jeenbaev of the National Academy of Science of Kyrgyz Republic.

07/28  Talk at the USGS/NASA Landsat Science Team Meeting, Brookings, SD.

9/14  Preliminary proposal submitted to NSF Partnership in International Research and Education (PIRE) program “Toward Resilient Communities in the Rural Drylands of Central and East Asia: Understanding the Impacts of Climatic Variability and Change, Demographic Dynamics, and Globalization”.

10/24-27  Global Land Project Open Science Meeting in Beijing. Henebry and Chi give separate talks on the project.

11/9-10  Henebry invited to present case study of modeling land surface phenology in mountains at the 3rd International workshop on Phenology and VI product validation, Ft. Collins, CO.

12/12-17  Presentations at the AGU Fall meeting in San Francisco, CA: (1) talk by Henebry “Livelihoods Poised Between Cold and Dry: Modeling Land Surface
Phenologies and Phenometric Lapse Rates in Central Asian Highland Pastures”, and (2) poster by Tomaszewska “Modeling the Seasonality of Snow Cover in Naryn Oblast, Kyrgyzstan”.

2017

4/9-13 Presentations at the US-IALE meeting in Baltimore, MD: (1) talk by Henebry “Using phenometric lapse rates in mountain landscapes to assess pasture condition & vulnerability”; (2) poster by Kelgenbaeva “Detecting change amidst uncertainty in digital elevation models: A comparison of SRTM and ASTER DEM products for two oblasts in the Kyrgyz Republic”; and (3) talk by Tomaszewska “Modelling the land surface phenology and seasonality of high-elevation pastures in Kyrgyz Republic”.

4/12-13 Presentations at the NASA LCLUC Science Team Meeting. Rockville, MD: (1) invited talk by Henebry “How Environmental Changes and Globalization Impact High Elevation Communities in Kyrgyzstan” and (2) poster by Kelgenbaeva “Detecting change amidst uncertainty in digital elevation models: A comparison of SRTM and ASTER DEM products for two oblasts in the Kyrgyz Republic”.

4/23-28 Poster at the European Geosciences Union meeting in Vienna, Austria by Henebry “Linkages between snow cover seasonality, terrain, and land surface phenology in the highland pastures of Kyrgyzstan”.

4/25 Invited talk at the Pan European Phenology (PEP725) Symposium: New Developments in Phenology. Zentralanstalt für Meteorologie und Geodynamik (ZAMF) in Vienna, Austria by Henebry “Linkages between snow cover seasonality, terrain, and land surface phenology in the highland pastures of Kyrgyzstan”.

5/20-25 Presentations at Japan Geosciences Union Annual Meeting, Makuhari Messe, Chiba, Japan: (1) talk by Kelgenbaeva “Environmental Changes in Central Asian High Elevation Communities: Land Surface Phenology and Snow Cover Seasonality in Kyrgyz Highlands”; and (2) poster by Kelgenbaeva “Detecting change amidst uncertainty in digital elevation models: A comparison of SRTM and ASTER DEM products for two oblasts in the Kyrgyz Republic.”

5/31 Talk at International University of Kyrgyzstan by Henebry “Linkages between snow cover seasonality, terrain, and land surface phenology in the highland pastures of Kyrgyzstan: Project update”.

6/2-5 Participation at invitation-only NASA-NSF-MSU Synthesis Workshop in Ulaanbaatar, Mongolia. Talk by Henebry “Ties that Bind: Dynamics of Remittance Networks in Central Asia”.

7/10-8/2 Field campaign in Alay and Chong-Alay rayons.

7/31 Talk at Mountain Societies Research Institute at the University of Central Asia in Bishkek by Henebry “Linkages between snow cover seasonality, terrain, and land surface phenology in the highland pastures of Kyrgyzstan: Project
update”. Exploratory meeting with researchers at the American University of Central Asia in Bishkek.

8/7 Second Progress Report submitted.

B. Project Personnel & Project Management (Updated)

The project team at South Dakota State University includes PI Henebry, Co-Is Chi and Groisman, post-doctoral fellow Kelgenbaeva, PhD student Tomaszewska, geospatial analyst Krehbiel, undergraduate research assistants Kane and Ali; Henebry, Ali, Kane, Kelgenbaeva, Krehbiel, and Tomaszewska are with the Geospatial Sciences Center of Excellence (GSCE). Post-doc Kelgenbaeva helped to write the proposal while she was at the International University of Kyrgyzstan. She arrived at the GSCE in December 2015. Krehbiel graduated with an MS in Geography from SDSU and joined the team in November 2015. He left the project in April 2016 to pursue an opportunity at the USGS EROS Center. Tomaszewska started a PhD program in Geospatial Science & Engineering at SDSU in January 2016. She joined the project in April 2016. She passed her written comprehensive examination in June 2017 and her oral comprehensive examination is scheduled for December 2017. Undergraduate research assistant Susannah Kane was employed during the summer months of 2016 and again in 2017. Ms. Kane worked in 2016 on entering data from paper questionnaires gathered in the July 2016 social survey effort in Naryn Oblast. In 2017, Ms. Kane has been working on gathering and analyzing remittance and migration data. Mr. Ibrahim was selected as a GSCE Center Scholar in January 2017. He has been working on analyzing the photo samples from the 2016 field campaign.

Our USGS collaborators Gesch and Danielson are engaged periodically as the situation warrants as they are not receiving any funding from the project. We maintain an active engagement with our regional collaborators Academician Prof. Dr. Aidaraliev, and Drs. Ibraimova, Khasankhanova, and Pulatov.

To date we have had five in-person project meetings: (1) an initial focused meeting with Henebry visiting the International University of Kyrgyzstan (IUK) in Bishkek in October 2015; (2) a larger meeting associated with April 2016 conference at the Kyrgyz Academy of Science in Bishkek. Dr. Tolib Mukimov of the Research Institute of Karakul Sheep Breeding and Desert Ecology, in Samarkand, Uzbekistan joined us at the Bishkek conference to discuss research opportunities in Uzbekistan. Dr. Alim Pulatov also presented at the Bishkek conference on possible research locations in Uzbekistan. Henebry, Chi, and Groisman all presented at the April 2016 conference as well; (3) a meeting in July 2016 at IUK to review preparation for the 2016 field campaign; (4) a focused meeting between IUK and Henebry in Bishkek in June 2017 to review biogeophysical findings from the 2016 field campaign and geospatial analyses, and to prepare for the July 2017 field campaign; and (5) a meeting at IUK on 13 July for Chi to review his findings from the 2016 social survey. In addition we have online meetings or phone call between the investigators as the occasion warrants.

C. Project Synopsis (updated)

Highlanders are different. People gestated, born, and raised at high elevation (>2500 m) exhibit distinct physiological characteristics, including increased blood viscosity due to higher hemoglobin content. Chronic physiological stress and lower reproductive success coupled with the
short growing season, long cold season, and harsh climatic extremes associated with the montane agro-pastoralism, make high elevation communities particularly vulnerable to additional stressors.

Prior to the Soviet era, highlanders in Central Asia practiced vertical transhumance to raising livestock, sheep and goats for wool, meat, milk, and hides. Collectivization disrupted this practice with multiple external subsidies. Since 1991 montane agro-pastoralism has been disrupted by withdrawal of external subsidies and introduction of a market economy.

Our project evaluates four aspects of environmental change in human settlements and associated summer and winter pasturelands in representative areas of Kyrgyzstan (KG) and Uzbekistan (UZ) since the 1970s and projected changes into the middle of the 21st century to assess impacts on these highland communities and the pastures upon which they depend. Our areas of interest are located in the Central and Southwestern Tien-Shan in the highlands of Osh and Naryn oblasts in southern KG. Due to political changes in UZ since the project was proposed, we have restricted data collection efforts to KG.

The four aspects of environmental change are
1) changes in the thermal regime including growing season timing and extremes,
2) changes in the moisture regime including peak precipitation timing and snow cover duration,
3) changes in socio-economic conditions including income, education, agricultural production and practices, and institutions, and
4) changes in land cover, land use, and land condition, including alterations in terrain from landslides and earthquakes.

Key response variables at the scale of human settlements in high elevation regions are the demographic profile (especially aging and gender), population outflow, fertility, and infant mortality, as these indicate the aggregate well-being of the communities. Key response variables for pasture condition are the temporal and spatial patterns of spectral indices based on remote sensing data from Landsat and MODIS.

An initial synthesis (Figure 1) leads us to pose the following linkages:
i) Increasing temperatures reduce snow cover duration and change the growing season in highland pastures, but more warmth may also reduce forage production;
ii) Increased remittances mean more livestock and more grazing pressure on nearby pastures, but not in remote highland pastures, which led to the declined status of lower pastures nearby human settlements and improved status of higher and more remote pastures; and
iii) Differential changes in pasture condition and increased remittances led to changes in community well-being, characterized by population decline, population aging, lower fertility rates, higher infant mortality rates, and higher international out-migration and internal migration.
Our fundamental question is whether change in pasture condition can be detected through remote sensing and linked to community well-being through econometric and structural equation modeling. The ancillary question of how climate change drives the change of pasture condition can be addressed through remote sensing of land surface seasonality (snow cover metrics) and land surface phenology (vegetation indices and careful analysis of precipitation station data complemented by remote sensing of precipitation and soil moisture. The linkage from remittances to community well-being will be tested through econometric and structural equation modeling. Impacts of climate change, changes in pasture condition, and increased remittances on community well-being will be used along with forecasted demographic changes to recommend policy strategies for building resilient communities.

Figure C-1. Conceptual framework: We are observing with Landsat and MODIS data the surface characteristics associated with the condition of highland pastures that are embedded in a landscape subject to both environmental and socio-economic forcings that influence land cover and land use.

D. Research Progress during Project Year 2

D.1. Remote Sensing of Land Surface Phenology in Mountains

A major development last year was the introduction and articulation of the concept of Phenometric Lapse Rates (PLRs). Recall that we focus on two phenometrics derived from the fitted parameter coefficients of the downwards convex quadratic (dCxQ) model of land surface phenology (viz., NDVI = α + β × AGDD – γ × AGDD²): Thermal Time to Peak (TTP) and Peak Height (PH). During the second project year, we advanced analyses of PLRs to four rayons in Kyrgyzstan. The results shown below are for At-Bashy rayon, but they are illustrative of the results from Naryn, Alay, and Chong-Alay rayons.

Figure D1-1 displays the persistent pasture resources in At-Bashy rayon. These pink pixels are the intersection of (1) the set of pixels successfully fitted (r²>0.5) to the dCxQ model for 14 to 16 years of Landsat and MODIS data during the period 2000-2015, and (2) the pasture category in a
Soviet era land use map updated by the Kyrgyz government in the past decade. These persistent pasture resources in the highlands serve as the landscape foundation of the montane agropastoralism of the region that relies on vertical transhumance. Thus, they are an appropriate target for close study. Figure D1-2 shows the coefficients for determination for the dCxQ LSP model. Figure D1-3 shows the distribution of northerly versus southerly aspects for the persistent pasture resources.

We expect that the PLR for the phenometric Thermal Time to Peak (TTP) would decrease with increasing elevation because the phenometric is a function of temperature. Figures D1-4 and D1-5 show the effect of aspect on PLR_{TTP} as a function of elevation for two slope categories.

It is evident that for slopes between 15° and 30° there is no significant difference in the PLR_{TTP} until the highest elevations (Figure D1-4). With steeper slopes, differences in average PLR_{TTP} become significant at lower elevations and it takes more AGDD to reach the peak NDVI on steeper northerly slopes (Figure D1-5).
Interannual variation in growing season weather affect the PLR\textsubscript{TT} as well, with a hotter, drier year (2007) showing a swifter decrease in TTP as a function of elevation than the cooler, wetter year (2009) (Figure D1-6). Steeper slopes exacerbate differences in aspect, even in a wetter year (Figure D1-7).
In contrast to PLR_{TTP}, we expect that PLR_{PH} would increase with increasing elevation, up to a point, because PH relates to vegetation that is limited by moisture availability during the growing season. In Figures D1-8 and D1-9, it is evident that average PLR_{PH} differs significantly by aspect until about 3400 m.

**Figure D1-6:**
PLR_{TTP} for contrasting years for slopes 15°-30°.

**Figure D1-7:**
PLR_{TTP} for contrasting years for slopes >30°.

**Figure D1-8:**
Average PLR_{PH} & 2SE for slopes 15°-30°.

**Figure D1-9:**
Average PLR_{PH} & 2SE for slopes >30°.
The difference in PLRs between cooler, wetter years and hotter, drier years for PH is striking. In Figure D1-10, the blue and yellow lines show little change in PLR_{PH} with elevation in the wet year of 2009, although there is a strong influence of aspect. Differences in aspect and elevation are clear in the drier year of 2007 (cyan and red lines). In steeper slopes (Figure D1-11), above 2900 m there is no difference in PLR_{PH} between the dry and wet years for northerly aspects (blue and cyan), but not for southerly aspects (yellow and red).

We are working on a manuscript for submission to *Remote Sensing of Environment* that introduces the concept and utility of PLRs and illustrates them using the data from the four focal rayons of Kyrgyzstan.

### D.2. Changes in Snow Seasonality in Kyrgyzstan

Soil moisture is critical for aboveground net primary production in these highland pastures; thus, we are evaluating on the seasonal dynamics of snow and their recent changes to document the changing highland environment. We have used MOD10A2 level-3 global “Maximum Snow Extent” 8-day composites at 500 m to determine (1) the first day of snow cover (FDoS), (2) the last day of snow cover (LDoS), and (3) the duration of snow cover (DoSC) each year from 2002 to 2015. We count the “snow year” starting at composite near the summer solstice and concluding 45 8-day composites later.

In addition to calculating the mean FDoS (Figure D2-1), LDoS (Figure D2-3), and DoSC (Figure D2-5), we applied non-parametric trend analysis using the Theil-Sen slope at two levels: p<0.1 (Figures D2-2, 4, 6) and p<0.05 (data not shown). Further, we calculated the pixel trend ratios for each snow seasonality metric as the number of significant negative pixels divided by the number of significant positive pixels. We expect the ratio to be close to unity if there are trend analysis results are randomly distributed.
Table D2-1: Pixel Trend Ratios for First Day of Snow

<table>
<thead>
<tr>
<th></th>
<th>Naryn</th>
<th>At-Bashy</th>
<th>Alay</th>
<th>Chong-Alay</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEG/POS p&lt;0.1</td>
<td>3.95</td>
<td>0.55</td>
<td>4.71</td>
<td>40.40</td>
</tr>
<tr>
<td>NEG/POS p&lt;0.05</td>
<td>4.11</td>
<td>0.60</td>
<td>7.19</td>
<td>93.36</td>
</tr>
</tbody>
</table>

Table D2-1 reveals that Chong-Alay rayon has many more negative trends in FDoS, meaning earlier onset of snow, than the other three focal rayons.
Figure D2-3: Last Day of Snow across Kyrgyzstan 2002-2015.

Figure D2-4: Trend in Last Day of Snow 2002-2015 for p<0.1.

Table D2-2: Pixel Trend Ratios for Last Day of Snow

<table>
<thead>
<tr>
<th></th>
<th>Naryn</th>
<th>At-Bashy</th>
<th>Alay</th>
<th>Chong-Alay</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEG/POS p&lt;0.1</td>
<td>137.69</td>
<td>128.28</td>
<td>1.84</td>
<td>1.43</td>
</tr>
<tr>
<td>NEG/POS p&lt;0.05</td>
<td>275.57</td>
<td>244.67</td>
<td>2.78</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Table D2-2 reveals that Naryn and At-Bashy rayons have many more negative trends in LDoS, meaning earlier melting of snow, than the other two rayons.
Table D2-3: Pixel Trend Ratios for Duration of Snow Cover

<table>
<thead>
<tr>
<th></th>
<th>Naryn</th>
<th>At-Bashy</th>
<th>Alay</th>
<th>Chong-Alay</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEG/POS p&lt;0.1</td>
<td>3.43</td>
<td>18.74</td>
<td>0.738</td>
<td>0.05</td>
</tr>
<tr>
<td>NEG/POS p&lt;0.05</td>
<td>4.04</td>
<td>23.95</td>
<td>0.64</td>
<td>0.024</td>
</tr>
</tbody>
</table>

Table D2-3 reveals that At-Bashy rayon has a shorter snow cover season (negative trend), but Chong-Alay rayon has a longer snow cover season (positive trend).
Discussion with the Chong-Alay rayon pasture committee head during the 2017 field campaign confirmed that the snow has been earlier and the duration of the snow cover has been longer over the past decade and a half, putting considerable constraints on the use of these pastures.

Note that the results above are for the Terra snow cover data. We have also analyzed the Aqua data and those results are less clear, likely due to the challenge of distinguishing cloud from snow with early afternoon illumination.

During fall 2017 we will be preparing a manuscript with these results and others extended to all rayons and oblasts across Kyrgyzstan.

D.3. Socio-Economic Analyses

The primary focus during the second project year for the social component has been to design and conduct field surveys in At-Bashy rayon in Naryn oblast and Alay rayon in Osh Oblast. Both field surveys include questionnaire surveys and in-depth interviews. The field work in At-Bashy rayon was conducted in July 2016 to study labor migration and left-behind children. We collected a total of 587 questionnaire surveys and 50 in-depth interviews. The field work at Alay rayon was just completed in July 2017. This work expands the questions to environmental change and pasture productivity and management. Co-I Guangqing Chi received an internal grant from Pennsylvania State University, which provided funds for purchasing 12 tablets, accessories, and software packages for data collection. By utilizing the tablets, we collected a total 1,233 questionnaire surveys and 51 in-depth interviews, a significant improvement over the cumbersome paper questionnaires used in the 2016 field campaign.

As our focus has been on survey design and data collection in the second project year, we do not yet have results to report. That said, we did some preliminary analyses of the At-Bashy data. Below is a brief summary of our preliminary findings.

Abstract

Labor migration serves as one adaptive strategy to alleviate poverty. As human society becomes more urban and more global, laborers migrate to cities and more developed countries to seek job opportunities; and this trend continues to grow. However, labor migration produces drastic impacts on left-behind children. This study investigates the impacts of labor migration on left-behind children in Kyrgyzstan, a country with international remittances counting for one-third of its GDP. The data analysis is based on nearly 600 questionnaire surveys and 50 in-depth interviews conducted in July 2016 in 12 mountain villages, all 2,000 meters above sea level. The preliminary analysis suggests that labor migration has negative impacts on the wellbeing of left-behind children, both directly and indirectly through marital relations. The impacts are more emotional for pre-school and elementary school students, and more behavioral for high school students. The negative impacts become stronger from district villages to smaller and more remote villages. Poverty and high unemployment rates are the primary driving factors of labor migration. The findings provide insights into the impacts of labor migration on left-behind children in a mountainous Central Asian country within the global context.

Introduction

Labor migration serves as one adaptive strategy to alleviate poverty. As human society becomes more urban and more global, laborers migrate to cities and more developed countries to seek job opportunities; and this trend only strengthens. However, labor migration produces drastic impacts
on left-behind children. Although the consequent remittances of labor migration help to battle poverty, the left-behind children suffer from missing parents, increased unsupervised time, deteriorating parent relations, and other vulnerabilities during child development.

This study investigates the impacts of labor migration on left-behind children in Kyrgyzstan based on survey data collected in July 2016. Kyrgyzstan is a small, landlocked, mountainous country in Central Asia. The population of Kyrgyzstan is largely rural, and heavily relies on the remittances from household members working abroad in Russia, Kazakhstan, or Europe. Kyrgyzstan is the second most remittance-dependent country in the world; remittances make up one-third of its GDP. In addition, Kyrgyzstan has very limited agricultural land—only 6.5% of the land is used for planting crops (Ibragimov & Asanaliyev, 1999). Further, Kyrgyzstan became independent of the former Soviet Union in 1991 and has experienced dramatic economic reform and changes in economic structure (Pankow & Jermakowicz, 1995), creating uneven poverty and unemployment.

![Figure D3-1. Villages visited in Naryn oblast in July 2016.](image)

**Data**

The data for this research comes from the 2016 field campaign in Kyrgyzstan. The purpose of the study was to examine the impacts of migration and subsequent remittance receipt on the sending households in some of the most remote, high-mountain communities in the world. The 2016 field research purposively sampled participants from the city of Naryn and 12 villages within At-Bashy rayon of Naryn oblast (Figure D3-1). The village populations range from 590 to 10,764 people, and are located along the mountain range from 2,000 to 2,500 meters above the sea level. Nearly 600 questionnaire surveys and 50 in-depth interviews were conducted. Most of the survey respondents and all of the in-depth interview participants had at least one household member who
had migrated. Each method queried respondents about their migrant family members, the receipt of remittances, and the impact of the migration and remittance receipt on left-behind family members and children.

**Expected Results**

In Figure D3-2, the many factors related to the migration of a household member are explored in a conceptual framework. Unemployment increases the likelihood of both the occurrence of poverty and the chance of a household member choosing to migrate. Poverty also increases the likelihood that a household member will migrate. Migration, in turn, affects the marital relationship between the migrant and his or her partner and the children left behind in the sending community. These are the relationships of particular interest to this study. Additionally, the quality of the marital relations between partners can impact the well-being of the left-behind children.

![Figure D3-2. A conceptual framework of labor migration and left-behind children](image)

In Figure D3-3, the left-behind children of migrations are explored by age groupings. The youngest children, those in elementary school, preschool, or younger, are likely to express effects of the absence of the migrant household member though emotional expressions. They may miss the migrant, particularly if the migrant is a parent, or exhibit shyness. Older left-behind children may express externalizing behaviors in the absence of a migrant family member. Some of these behaviors may include smoking or drinking, regular tardiness or absence from school, or fighting with peers and family members. Additionally, migration may be a disincentive to stay at home, and may increase the likelihood of the left-behind youth living or staying with friends.

Figure D3-4 further explores the relationship between migration and the children left behind in sending communities by examining how characteristics of the sending community, particularly the combined impacts of size and location of the village can worsen negative impacts on left-behind children.
Conclusions

The preliminary analysis suggests that labor migration has negative impacts on the wellbeing of left-behind children, both directly and indirectly through the marital relations. The impacts are more emotional for pre-school and elementary school students, and more behavioral for high school students. The negative impacts become stronger from district villages to smaller and more remote villages. Poverty and high unemployment rates are the primary driving factors of labor migration. The findings provide insights into the impacts of labor migration on left-behind children in a mountainous Central Asian country within the global context.

Works cited in Section D.3

D.4. Communicating Research Results

The team was busy communicating research results during Project Year 2. We delivered 7 invited talks, 10 contributed talks, 5 posters and 1 webinar. In addition, two proceedings papers from the International University of Kyrgyzstan April 2016 conference were published in the Journal of the International University of Kyrgyzstan and a journal article was published in 2017 in Ecological Indicators by a masters student at the University of British Columbia, on whose advisory committee Henebry served. The article describes research about pasture conditions in Naryn oblast. Three manuscripts are in preparation for submission during fall 2017, including one describing PLRs, another describing the results of the trends in snow seasonality, and a third describing the comparative dynamics of remittance networks.

PI Henebry served as guest editor (along with Drs. Forrest Hoffman and Jitendra Kumar of ORNL and Dr. Xiaoyang Zhang of SDSU) for a special issue of Remote Sensing entitled “Land Surface Phenology and Seasonality: Novel Approaches and Applications” (http://www.mdpi.com/journal/remotesensing/special_issues/phenology). The special issue featured 14 papers published in 2017.

E. Plans for Third Project Year

The third project year already commenced with a field campaign in rayons of Alay and Chong-Alay (and three summer pastures in Kara-Suu rayon). Field sampling include characterization of the spatial patterns in pastures using (1) nadir-viewing digital photographs, (2) landscape characterization using the Ricoh Theta S 360° camera to generate VR-enabling spherical photographs, and (3) surficial soil moisture measurements using a Dynamax Thetaprobe. The purpose of these measurements and the complementary set obtained during the 2016 field campaign is the quantification of sub-pixel (<30 m) heterogeneity in pastures of different time and intensity of grazing. Figure E-1 shows an example of the digital photo sampling; Figure E-2 shows the layout of the basic 30m x 30m sampling cell; Figure E-3 shows the 2x2 sampling grid; and Figure E-4 shows the pasture locations and their elevations sampled during the 2017 field campaign.

Figure E-1: Example of digital photo sampling. The orange ring covers 0.25 m². This pasture is actively grazed and closely cropped during the summer by horses. Elevation is ~2419 m.
**Figure E-2:** Layout of the basic 30m x 30m grid cell with 11 sampling points and the sampling route. The asymmetry along diagonals helps in-field navigation.

Multiple grids can be built up from this basic cell: 2x1, 2x2, 2x3, 3x3, etc.

**Figure E-3:** Layout of the 2x2 (60m x 60m) sampling grid for digital photos (in 2016 &2017) and soil moisture measurements (in 2017 only). It takes an experienced team of 4 about 90 minutes to set-up and sample a 2x2 grid, depending on the height of the vegetation, the wetness of the surface, and slope of the grid.

Samples are taken close to each blue point: 44 for a 2x2 grid. A 2x2 grid generates 924 unique pairwise comparisons from which to generate a semivariogram to characterize the spatial heterogeneity at the subpixel scale.

During the 2017 field campaign, the team sampled 36 – 2x2 grids and 3 – 2x1 grids. Of the 36 there were 21 in Alay, 12 in Chong-Alay, and 3 in Kara-Suu rayons, and there were 4 – 2x3 grids that were composed of paired 2x2 grids with overlap for error analysis. During the 2016 field campaign, the team sampled 17 – 2x2 grids and 2 – 3x3 grids for a total of 25 – 2x2 grids (each 3x3 grid is composed of 4 – 2x2 grids). During the third project year, we will be processing all of the photo data to link the subpixel heterogeneity with timing of pasture use and pasture condition and with the spatiotemporal “texture” of the corresponding Landsat data.
We will also be preparing manuscripts on the phenometric lapse rate concept, on the shifts in snow seasonality, and on the linkage between snow season and land surface phenology.

Doctoral student Monika Tomaszewska will be submitting a NESSF proposal in early 2018 about the linkage between snow cover and subsequent pasture growth.

We intend to present our new results at the 2017 AGU Fall Meeting in New Orleans and the NASA LCLUC Science Team meeting in April 2018.

During the third project year, the social research will shift focus to analyzing the survey data collected from At-Bashy rayon in Naryn oblast in 2016 and Alay rayon in Osh oblast in 2017. Our data include quantitative survey data, qualitative in-depth interview data, and spatially referenced data (for Alay rayon only). Our data cover environmental change, pasture productivity and management, labor migration, remittance, left-behind children, and family relations. The rich data that we collected enable us to analyze the complex relations among these elements. We aim to develop at least three manuscripts based on these rich datasets. New results will be presented at the 2017 Central Eurasian Studies Society meeting in Seattle in October and at the XXVIII IUSSP International Population Conference in Cape Town in November 2017.

F. Cumulative project publications in reverse chronological order


G. Cumulative project presentations in reverse chronological order (8 invited talks, 13 talks, 5 posters, 1 webinar = 27 total)


