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CONTEMPORARY GLOBAL CLIMATIC CHANGES AND THEIR MANIFESTATION IN THE DRY LAND BELT OF NORTHERN EURASIA

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СОВРЕМЕННЫЕ ГЛОБАЛЬНЫЕ КЛИМАТИЧЕСКИЕ ИЗМЕНЕНИЯ И ИХ ПРОЯВЛЕНИЯ В ЗОНЕ СУХОЙ ЗЕМЛИ СЕВЕРНОЙ ЕВРАЗИИ

Аннотация: *Зона сухих земель (ЗСЗ) в среднеширотном Евразийском континенте является самой большой внетропической сухой областью в мире, отделенной несколькими азиатскими горными хребтами. Пояс простирается по пустынным, полупустынным территориям, степям, лесным степям, а южная часть умеренной лесной зоны к северу от 37^{0}N с Венгрии на запад по всей Средней Азии до Монголии и Северо-восточного Китая на востоке. Существуют опасения, что в будущем ЗСЗ станет еще суше. Действительно, в последние десятилетия ЗСЗ претерпела кардинальные изменения в связи с увеличением темпов климатических изменений, которые изменили частоту и интенсивность экстремальных явлений, водоснабжения, а также состояние регионального криосферы. Все эти изменения произошли в контексте социально-экономических сдвигов, которые привели к резким и масштабным изменениям землепользования. Наша презентация будет сосредоточена на эмпирических данных о последних климатических изменениях по всему земному шару, и как они проявляются в ЗСЗ. Мы показываем последствия непропорционального потепления Арктики, которые меняют меридиональный градиент поверхностной температуры воздуха, и обсуждаем, как это изменение повлияло на транспортировку водяного пара в евразийский Континент.* ***Мы*** *показываем, что скорость потепления в ЗСЗ является одним из высоких по всему земному шару, и обсуждаем, как это потепление влияет на состояние криосферы* *(сезонные снежные покровы и отступления ледников), сезонный цикл вегетации (особенности сельскохозяйственного сезона), и земной водный баланс. Мы показываем распределение осадков, которые наблюдались во всем мире и обсуждаем как эти изменения могут вызвать негативные последствия для сельского хозяйства, лесоводства, производства животноводческой продукции и водоснабжения. Заморозки ("гололед", в России) являются опасными явлениями, влияющие на многие аспекты человеческой деятельности. Показано, что частота этих событий в течение последних десятилетий сократилась в ЗСЗ вместе с продолжительностью отопительного сезона. Таким образом, в горных регионах (например, в Кыргызстане выше 2000 м над уровнем моря) заморозки происходят все чаще.*

Ключевые слова: *изменение климата, зона сухой земли, Северная Евразия, воздействие на окружающую среду.*

Abstract: *The Dry Land Belt (DLB) in the mid-latitude Eurasian continent is the world's largest extratropical dry area mostly separated by several Asian mountain ranges from the moisture influx from the tropics and the Pacific Ocean. The Belt stretches over deserts, semi-desert areas, steppes, forest-steppes, and the southern part of temperate forest zone north of 37°N from Hungary on the west throughout the Central Asia to Mongolia and Northeastern China on the east. There are concerns based on the GCM projections that in the future the DLB may become even drier. Indeed, in recent decades the DLB has undergone dramatic changes due to increased rates of climatic changes that altered the frequency and intensity of extreme events, the water supply, and the state of regional cryosphere. All of these changes have occurred within a context of socioeconomic shifts that have produced abrupt and large-scale land use changes. Our presentation will focus on empirical evidence of recent climatic changes over the Globe and how they manifest themselves in the Dry Land Belt. We show the consequences of the disproportional Arctic warming that changes the meridional gradient of the surface air temperature and discuss how this change has impacted the water vapor transport into the interior of the Eurasian Continent. We show that the rate of the warming in the DLB is among the largest over the Globe and discuss how this warming affects the state of the cryosphere (seasonal snow cover and glaciers' retreat), the seasonal cycle of vegetation (the characteristics of the growing season), and the terrestrial water budget. We show the observed tendencies of changes in the intra-annual precipitation distribution that have been observed world-wide, and discuss how these changes can cause negative consequences for agriculture, sylviculture, livestock production, and water supply. Freezing events ("gololed", in Russian) are hazardous phenomena affecting many aspects of human activity. We show that the frequency of these events during the past decades has been decreasing in the lowlands of DLB along with the duration of the cold season. However, in the mountainous regions (e.g., in Kyrgyzstan above 2000 m ASL) freezing events have become more frequent.*

Keywords: *climate change, dry land belt, Northern Eurasia, environmental impacts*

1. Introduction

The Dry Land Belt (DLB) in the mid-latitude Eurasian continent is the world's largest extratropical dry area mostly separated by several Asian mountain ranges from the moisture influx from the tropics and the Pacific Ocean. The Belt stretches over deserts, semi-desert areas, steppes, forest-steppes, and the southern part of temperate forest zone north of 37°N from Hungary on the west throughout the Central Asia to Mongolia and Northeastern China on the east **(Figure 1).** Scientific investigations on DLB have been carried on within the foci of two high priority international initiatives: Northern Eurasia Earth Science Partnership Initiative (http://neespi.org/; Groisman et al. 2009) and Monsoon Asia Integrated

Regional Study (http://www.mairs-essp.org/) and are now continued under the *Future Earth in Asia* initiative (http://www.futureearth.org/asiacentre/).

There are concerns based on the GCM projections (cf., Manabe et al. 2004) that in the future the DLB may become even drier. Indeed, in recent decades the DLB has undergone dramatic changes due to increased rates of climatic changes **(Figure 2)** and disproportional temperature changes in high latitudes (in the Arctic; **Figure 3)** have reduced the meridional temperature gradient in the Northern Hemisphere (Groisman and Soja 2009). This gradient controls the westerlies

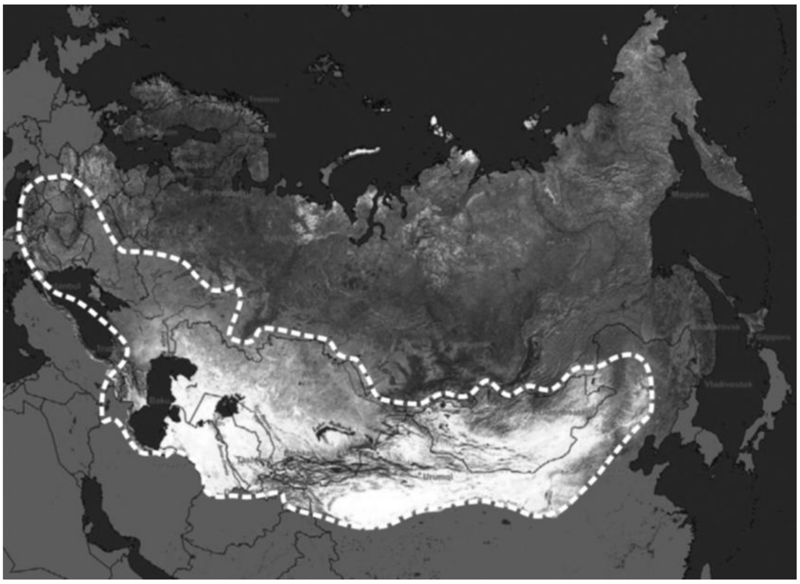

Figure 1.

that transport heat and water vapor from North Atlantic Ocean and the Arctic Seas into the interior of Northern Eurasia during most of the year. The weaker this gradient is, the stronger the meandering of the westerlies and more chances for atmospheric blocking over the continent interiors have been observed (Schubert et al. 2014).

2. Data and Methods

In our analyses, we used Global mean monthly surface air temperature archive (Lugina et al. 2006, updated to 2014); routinely updated Global Historical

Climatology-daily Data Set (GHCN-daily; Menne et al. 2012); archive of extratropical cyclone tracks retrieved by Tilinina et al. (2013) from the latest generation of Atmospheric Reanalyses; hourly surface synoptic station data from the Integrated Surface Database (ISD; Smith et al. 2011; supplemented with additional data from the Russian and Norwegian national archives); and the runoff data accumulated at the University of New Hampshire (http://neespi.sr.unh.edu/maps/).

Our data analyses (e.g., those shown in Figures 2, 3 and 4) are based on area-averaging routines of long-term time series specially processed to secure representative mean regional anomalies of area-averaged variables such as surface air temperature, duration of the growing season, precipitation characteristics, etc. (for more about these methods please see Vinjikov et al. 1990; Groisman et al. 2013).

Our assessment of the number of cyclone tracks (shown in Figure 5) began with selection of a region within the Central Asia region, Sector [40°N – 50°N; 50°E – 90°E], and counting of the number of individual extratropical cyclones, whose tracks crossed the Sector boundaries. These cyclones carry different amounts of water vapor and may not necessarily cause precipitation events within the Sector. However, they are a prerequisite for the outside water vapor transport into the Sector and indirectly characterize the regional precipitation amount.

Our analyses of the freezing rain days are based on the specific Present Weather Code (PWC) variable that adheres to WMO standards (WMO 2004) and is available in synoptic national and international archives listed above. We counted days with freezing events that were defined as days with *at least* one such event. Thus, two separate freezing drizzles in a given day were counted only once.

3. Results

3.1. Large scale temperature changes and their impact. Analyses of the large scale temperature changes during the period of instrumental observations over DLB (Figure 2) show that the mean rates of winter and spring temperature increase have been among the largest in the world (2.2ºC and 2.0ºC per 134 years, respectively), but summer temperature changes are statistically insignificant, *except for* *the last 2 decades* when they increased by 1ºC. A steady spring warming causes earlier onsets of the growing season in DLB (cf., Figure 4). In the DLB, the growing season is long enough and its further increase means that precipitation increases should balance the increased vegetation water demand or drier weather conditions will occur which negatively affect existing vegetation and shift its spatial pattern. This is especially relevant in the past two decades when summer temperatures have increased and worsened the water deficit in the Continent interior.

The winter season warming in the DLB was also substantial but non-linear (Figure 2). It is corroborates well with the Arctic warming in the last decade that promoted more winter anticyclonic conditions over the interior of Eurasia (Newson 1973; Mokhov et al. 2014). These anticyclones in winter means cold outbreakes that contribute to mean seasonal temperature changes shown in Figure 2.

3.2. Arctic and changes in atmospheric circulation in the extra-tropics. The last decade in the Arctic was extraordinary warm (Figure 3). It affected the penetration of the extratropical cyclones into the interior of the continent. In the summer season, this process was not linear. In some years, there were more cyclones than usual and in other years there were a much less than usual number of these cyclones. Figure 5 illustrates these peculiarities of the cyclone tracks' behavior in the Central Asia derived from the latest Atmospheric Reanalyses developed in the United Kingdom (ERA-interim) and in the USA (MERRA) for the summer season. Globally, the meandering of the extratropical cyclone tracks corresponds (among other reasons) to a new mode of precipitation patterns observed across the extratropics (Figure 6).

3.3. Summer warming and the cryosphere. Krenke (1982) derived the glaciers' balance as a function of summer temperature at the snow line of the glacier and the annual precipitation totals on its surface above this line. The quantitative estimates Kenke made mostly in the Central Asian glacier systems. Among these findings was that an increase of summer temperature at the snow line by 1°C should be compensated by about 10% increase in annual precipitation.

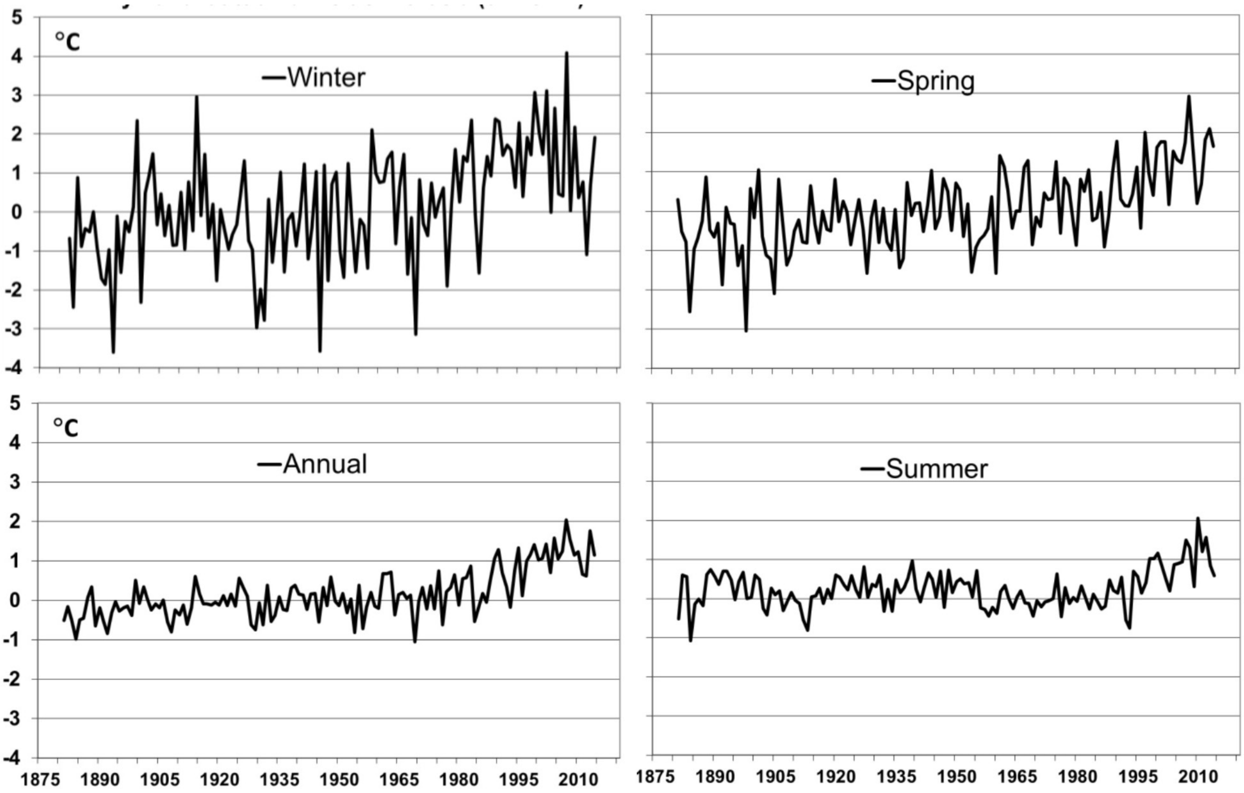

Figure 2. Mean winter, spring, annual, and summer surface air temperature anomalies during the 1881-2014 period area-averaged over the DLB (reference period 1951-1975; archive Lugina et al. 2006, updated). Autumn changes are similar to those in summer but with higher variability.

Both these quantities are practically unmeasured at the existing meteorological networks of the Central Asian countries. However, we can extrapolate the observed warming at the elevations of the existing network upward to the slopes. The observed evidence of the glaciers' retreat (Aisen and Aizen 2014; Syromyatina et al. 2011) supports the general tendency of the temperature-related retreat of the glaciers in Central Asia that cannot, so far, be mitigated by a corresponding increase of precipitation at high elevations.

3.4. Freezing events over Kyrgyzstan. Currently, the changes of the frequency of freezing events during the past 4 decades have been studied only over six countries. These include Canada, USA, Russia, Norway, Kyrgyzstan, and Belarus. The first publication that includes the results for the first 4 countries in this list is Groisman et al. (2016). Here we present our pilot results for Kyrgyz Republic using the synoptic data from 1966 to 2008 for 26 synoptic stations of this country. Table 1 shows a significant (threefold) increase in the freezing events frequency at high altitudes of the nation.

3.5. Streamflow changes in the Central Asia River Basins

Revealing climatic changes in Central Asian runoff has never been a pleasant exercise. Water withdrawals for irrigation and other needs are very high and for many decades these withdrawals were reported unscrupulously. Current reports show decreasing discharge tendencies in the downstream of large rivers, Amu Darya and Syr Darya. However, upstream annual discharge variations show no trend

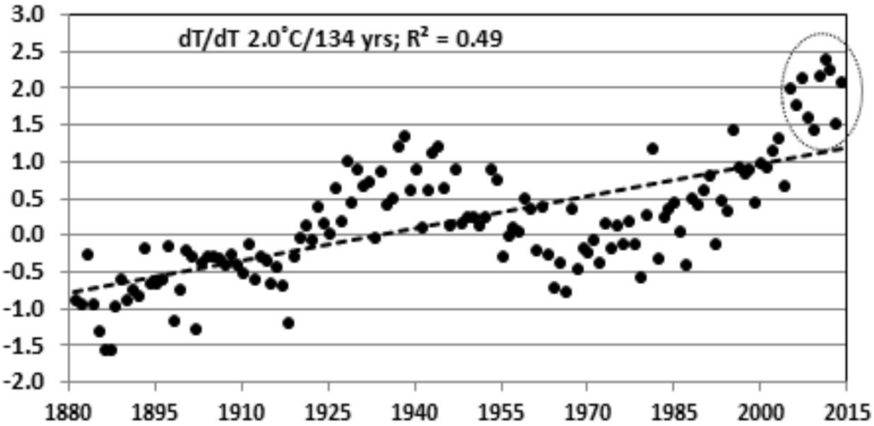

Figure 3. Annual surface air temperature anomalies (°C) area-averaged over the 60°N – 90°N latitudinal zone during the period of mass-instrumental records from 1881 to 2014 (Lugina et al. 2006, updated).

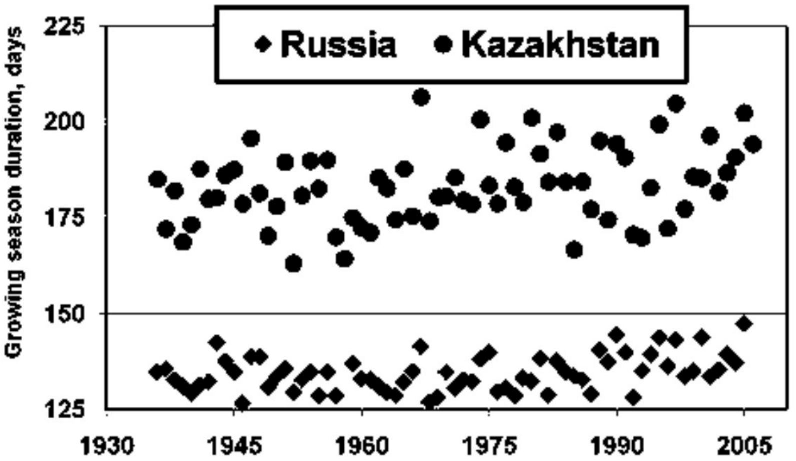

Figure 4. Duration of the growing season area-averaged over Russia (rombs) and Kazakhstan (dots). It shows that during the past 70 years, there were significant increases in the length of this season by 6 to 11 days (or by 5% to 6%) respectively over these two countries.

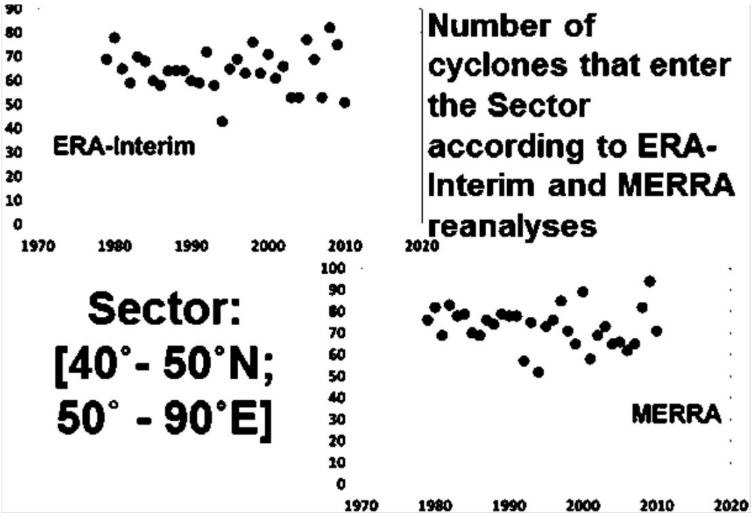

Figure 5.

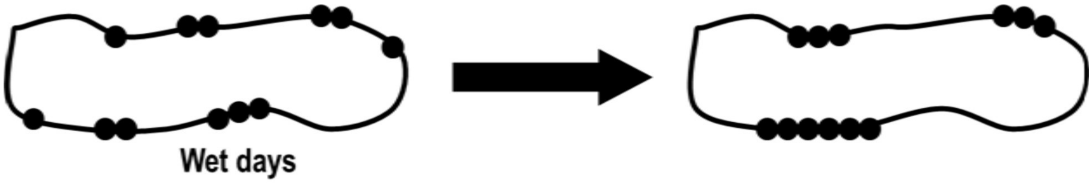

Figure 6. Beads with a fixed number of stones illustrate how we can have in the same region simultaneous increases in prolonged Wet Day and Dry Day Periods even with unchanged precipitation totals (design by O.G. Zolina). This kind of redistribution of precipitation events has been documented over most of northern extratropics from southern Canada and USA to Europe, Russia, and Japan (Groisman et al. 2013).

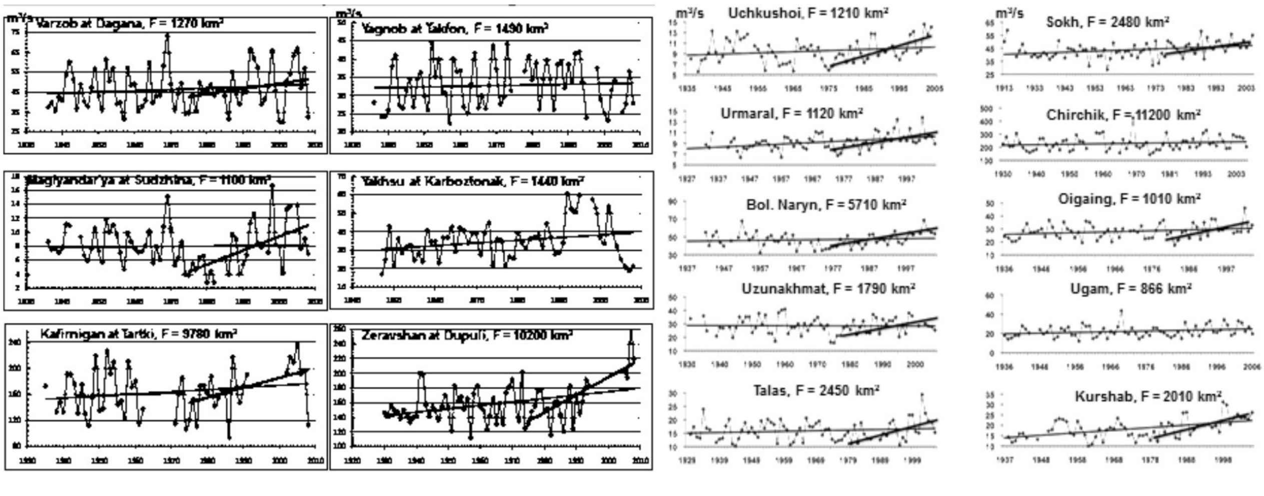

Figure 7. Pamir Mountains and Amu Daria (left) and Tian Shan Mountains and Syr Daria (right) upstream annual discharge variations.

or even increases in the last decades especially in the Tian Shan Mountains (cf., Figure 7). We cannot say with confidence if these increases are of natural origin (due to precipitation increase or glaciers' melt) or if they are due to reduction of agricultural activity in the River Basins.

4. Discussion and Conclusions

4.1. Generally speaking, the ongoing climatic changes in the DLB such as mild winters with frequent thaws; earlier spring onset; longer vegetation season; warmer

summers; and no significant change in precipitation, promote water supply deficit.

The observed and projected temperature changes altered the frequency and intensity of extreme events (Groisman et al. 2009, Soja et

Table 1.

Climatology of the annual frequency of all freezing precipitation events (freezing rain, freezing drizzle, and ice rain) over Kyrgyzstan during the 1966-1990 period and recent changes in this frequency during the 21st century (only data for the 2000-2008 period have been available for this analysis).

Freezing events at different elevation	below 1 km	from 1 to 2 km	above 2 km
Climatology	1.03	0.63	0.31
Changes between two periods	-0.24	0.24	1.07

al. 2007; Shiklomanov et al. 2007, Zhai et al. 2004; Barriopedro 2011; Schubert et al. 2014). These disturbances include, but are not limited to, widespread droughts, unprecedented floods, dust storms, massive melting of the glaciers, and wild fires in both steppe and forests. The changes have occurred within a context of socioeconomic shifts that have produced abrupt and large-scale land use changes. All these aspects of contemporary environmental change must be thoroughly studied and monitored.

4.2. Our special concern is a decreasing ability of regional observing systems to monitor the ongoing changes, especially at high elevations. We have new tools to monitor (e.g., remote sensing instrumentation) but to utilize the new products in context of climatic change is still a challenge.

4.3. Regional societal sustainability within the DLB is at risk because, unlike other dryland regions, it is densely-populated and diversely governed by contrasting political systems. Some of these systems are “in transition” and have not yet established sufficient resilience to withstand social and environmental extremes (Lioubimtseva and Henebry 2009). Collapse of the former USSR and the rapid economic expansion in China have produced changes to the land surface that have not been comprehended by physical models alone. The environmental consequences and pathways of recovery of multiple (and unique) extreme socioeconomic disturbances in the region therefore merit further thorough scientific analysis supported by environmental and climatic monitoring.

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