Changes of Snow Cover Characteristics in Central Asia between 1986 and 2012 derived from AVHRR and MODIS time series

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ABSTRACT

Central Asia with its continental climate is threatened by a continuously aggravating water scarcity – due to climate change on the one hand and the effects of anthropogenic influences on the other hand. As most precipitation accumulates during winter and early spring seasons, snow contributes the major part of available fresh water. The aim of the presented study is therefore to analyze snow cover conditions as derived from remotely sensed data for the longest possible time series in order to detect possible changes in snow cover characteristics. This analysis is based on observations originating from Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) data and starts in the year 1986, incorporating daily snow cover datasets until the year 2012. Though no significant trend in snow cover duration was identified from these 26 year time series, a shift towards earlier snow cover onset and earlier snow cover melt was detected within the mountainous regions. As these regions conform to the origin of Central Asia's most important rivers – Amu Darya and Syr Darya – the observed changes may pose a serious challenge to the water management authorities.

Keywords: MODIS, AVHRR, snow cover duration, snow cover, Central Asia, climate change, time series analysis

INTRODUCTION

Central Asia comprises an area of ~ 4,000,000 km², containing Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan (Figure 1). The continental climate is characterized by hot and dry summer months and cold winter seasons with most precipitation occurring during winter and early spring (Klein *et al.*, 2012, Lioubimtseva & Henebry, 2009). Amu Darya and Syr Darya Rivers originate from the mountainous regions of Tian Shan and Pamir in the South and South-East of Central Asia and constitute the major source of fresh water for the region (V. B. Aizen *et al.*, 1995, Glantz, 2005). Increasing demands for hydropower generation, irrigation, and the growing population are opposed to the limited and most valuable water resources, meaning that possible effects of climate change may have serious impacts on the region (Vladimir B. Aizen *et al.*, 1997, Mokhov *et al.*, 2006). The aim of the study was therefore to analyze long-term trends of Snow Cover Duration (SCD), Early Season SCD (SCD_{ES}), and Late Season SCD (SCD_{LS}), as such changes would inevitably affect the water availability within Central Asia. On a global scale, climate change generally causes decreased SCD (Barry, 2008, Brown & Mote, 2009, Brown, 2000), though also contrary developments towards increased SCD are possible – depending on the

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location and the prevailing changes in temperature and precipitation (Räisänen, 2007). Remotely sensed data are suited to map snow cover parameters like SCD, SCD_{ES}, and SCD_{LS} on a daily basis and with a spatial resolution that conforms to the requirements expressed within the Global Climate Observing System (GCOS, (Dietz, Kuenzer, *et al.*, 2012, WMO & GCOS, 2011)).

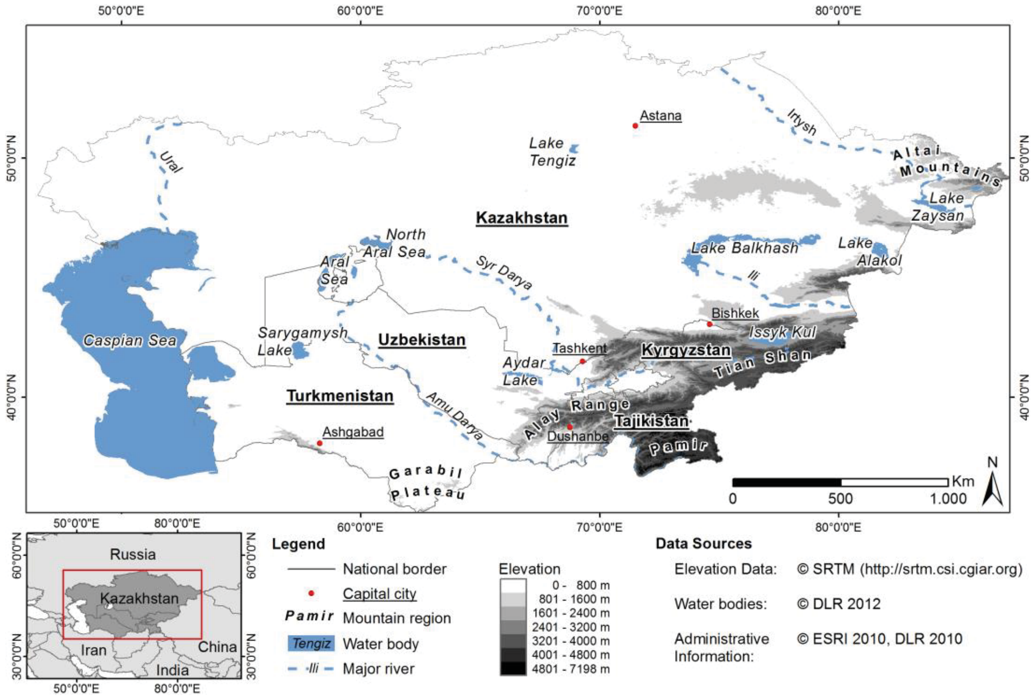

Figure 1: Overview of Central Asia

DATA AND METHODS

AVHRR Local Area Coverage (LAC) Level 1B (obtained from www.class.noaa.gov) and MODIS daily snow cover products MOD10A1 and MYD10A1 (obtained from http://nsidc.org/data/) served as data basis for the presented study. 27.000 AVHRR scenes were available for download between 1986 and 2000, whereof 20.300 could be processed and analyzed. The remaining 6.700 files contained night time observations or corrupt data. To extract information about snow covered and snow free ground from the raw Level 1B data we calibrated and navigated each orbit with Terascan and applied the AVHRR Processing Over Land cLoud and Ocean (APOLLO) scheme to derive the snow classification (Gesell, 1989). The result is comparable to the operational Level 3 MOD10A1 and MYD10A1 snow cover products (Hall *et al.*, 2002) provided by the National Snow and Ice Data Centre (NSIDC), though resolution (1.1 km for AVHRR compared to 0.5 km for MODIS), geolocation accuracy (shifts of up to 2 pixels possible for AVHRR), and classification clear-sky accuracy (~ 90% for AVHRR and ~ 93% for MODIS (Hall & Riggs, 2007)) differ between the two sensor families.

Because clouds obscured up to 70% of winter season observations in northern Kazakhstan, cloud cover had to be removed in order to be able to analyze for parameters like SCD, SCS, and SCM. We applied four successive steps to the thematic snow cover maps: A combination of all available observations for each calendar date; a temporal gap-filling algorithm including three consecutive days (one day prior and one day after the actual date); a topography-dependent snow line filter, detecting upper and lower snow lines according to Parajka *et al.* (2010); a seasonal filter incorporating a complete hydrological year. Similar steps have been applied for a study in Europe (Dietz, Wohner, *et al.*, 2012) and Central Asia (Dietz *et al.*, 2013) before, thou these studies only relied on MODIS snow cover products as data source. By adding AVHRR, the time series could be extended back to 1986.

The cloud-free daily snow cover products form the data basis for the calculation of SCD, SCD_{ES}, and SCD_{LS}. These parameters are derived relying on equations (1) to (3):

$$SCD = \sum_{i=0}^{N} (D_{i2} - D_{i1}) \quad (1)$$

$$SCD_{ES} = \sum_{ES=0}^{NES} (D_{ES2} - D_{ES1}) \quad (2)$$

$$SCD_{LS} = \sum_{LS=0}^{NLS} (D_{LS2} - D_{LS1}) \quad (3)$$

where N (NES, NLS) is the number of days per hydrological year (Early Season, Late Season) while Di1 (D_{ES1}, D_{LS1}) and Di2 (D_{ES2}, D_{LS2}) refer to the beginning and ending dates of the hydrological year (Early Season, Late Season), respectively. The beginning of a hydrological year is set to September 1st while the switch between early and late season is chosen to fall on January 15th of a respective year.

RESULTS

For each year between 1986 and 2012, SCD, SCD_{ES}, and SCD_{LS} have been calculated according to equations (1) to (3). Because the availability of AVHRR data is limited for the years before 1993 especially for northern Kazakhstan, results for this region are only reliable after the beginning of the hydrological year 1993/1994. Mean snow cover parameters were derived for multiple years as well as single year maps of SCD, SCD_{ES}, and SCD_{LS}. The analysis of linear trends in SCD, SCD_{ES}, and SCD_{LS} did not produce any significant results when referring to a pixel scale. One reason is the relatively high variability of snow cover parameters between individual years. Years with long SCD, SCD_{ES}, or SCD_{LS} are often followed by the contrary. The time series of only 26 years is too short to compensate these outliers. Another problem is the geolocation uncertainty of ± 2 AVHRR pixels, which can compromise the results especially in mountainous regions where pixels with long SCD (ridges) are often situated near pixels with low SCD (valleys). Therefore, analysis of possible snow cover trends was also derived on a catchment basis. Mean SCD, SCD_{ES}, and SCD_{LS} were calculated for these hydrological entities, rendering the results insusceptible to single pixel shifts. Though SCD still does not show evidence of any trend between 1986 and 2012, SCD_{ES} increases within the upstream regions of Amu Darya and Syr Darya Rivers while at the same time, SCD_{LS} is decreasing. Figure 2 and Figure 3 illustrate the long term changes of SCD_{ES}, and $SCD_{LS,}$ respectively. The parameters have been averaged to 8-year means in order to compensate for single outliers, again. The charts contain mean $SCD_{ES/LS}$ for 1986-1993 (blue column on the left), 1994-2003 (red column in the center), and 2004-2012 (green column on the right). In Figure 2, the development towards longer SCD_{ES} is obvious for most of the upstream catchments of Central Asia. Contrary, Figure 3 indicates shorter SCD_{LS} while time proceeds. This explains why SCD in general stays more or less stable and does not follow any significant trend.

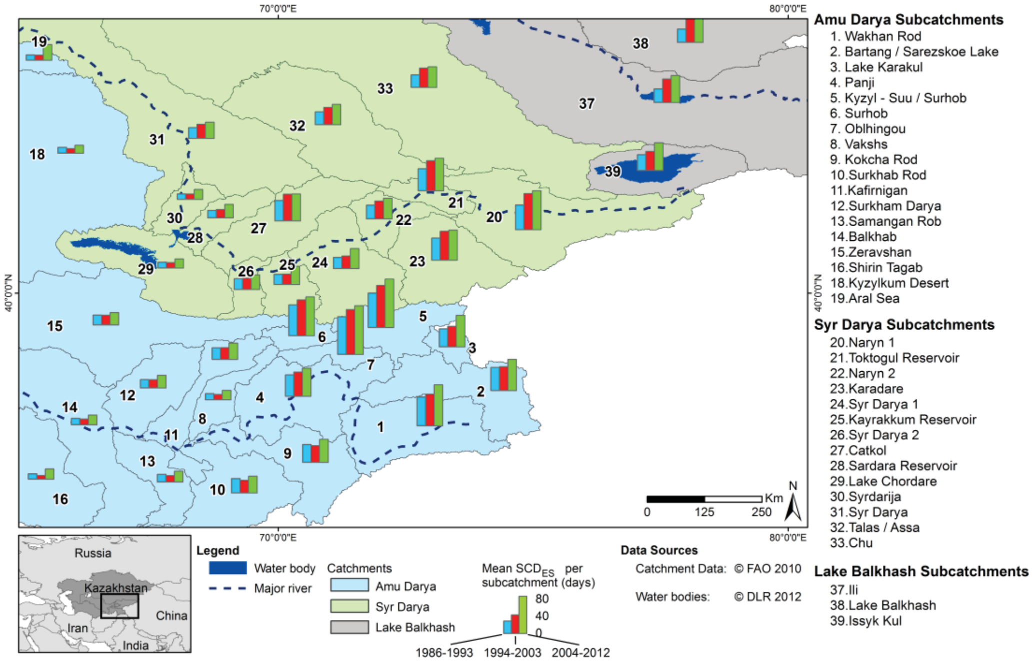

Figure 2: Long term changes in Early Season Snow Cover Duration

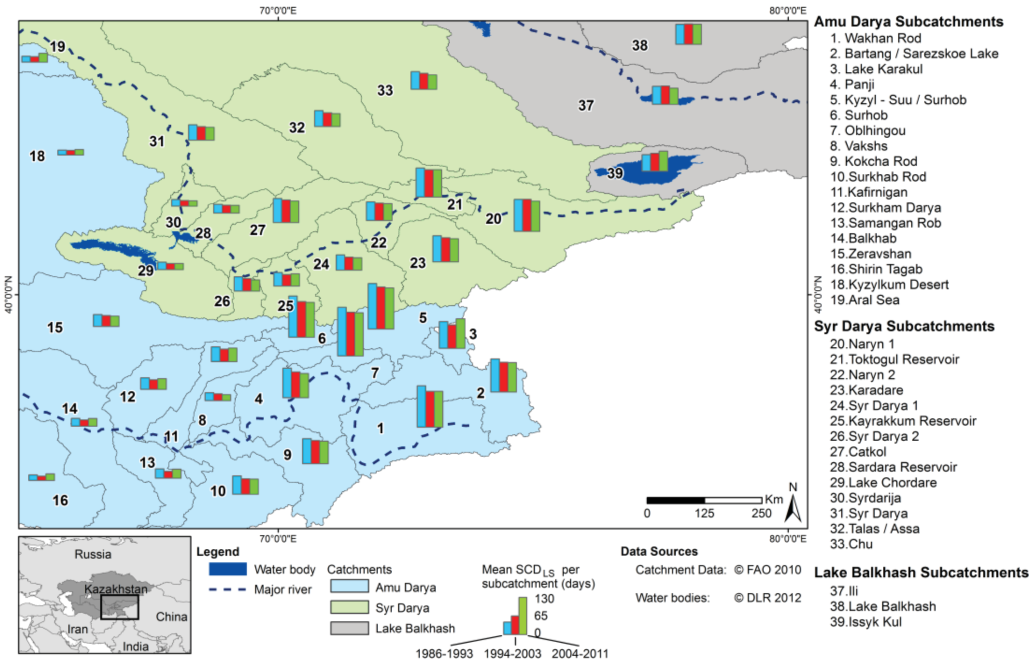

Figure 3: Long term changes in Late Season Snow Cover Duration

The consequences of the observed changes may be wide-ranging: As stated in the introduction, Central Asia's fresh water supply is strongly depending on the flow of Amu Darya and Syr Darya. Since both rivers originate in the area depicted in Figure 2 and Figure 3, shifts in SCD towards earlier start and earlier melt will also cause a shift in the runoff behavior of these rivers. This development may be driven by increasing temperatures caused due to a changing climate

(Lioubimtseva & Henebry, 2009), which would mean that the observed changes may aggravate during the upcoming decades.

CONCLUSIONS

Twenty-six years of daily snow cover datasets were processed and analyzed for the region of Central Asia based on 1.1 km raw AVHRR LAC data and the operational 500 m MODIS daily snow cover products MOD10A1 and MYD10A1. After cloud coverage has been removed by applying four successive gap filling techniques Snow Cover Duration as well as Early and Late Season Snow Cover Duration have been derived for each year. Though data gaps in the northern parts of Kazakhstan prevent detailed analyses in these regions before 1993, the mountainous regions of Tian Shan and Pamir Mountains could be investigated for possible long term changes in snow cover characteristics. This analysis revealed that the overall Snow Cover Duration did not change significantly within the upstream regions of Amu Darya and Syr Darya Rivers. A shift towards earlier snow cover onset and earlier snow cover melt could be identified for this region that evolved since 1986. As the fresh water availability of Central Asia is strongly depending on the snow cover conditions within the mountains, this development may have significant impacts on the amount of water and the point in time when the peak runoff occurs, affecting reservoir management, irrigation, hydropower generation, and political stability.

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