

Snow cover characteristics for the hydrological Volga sub-basins and their influence on spring floods in the Republic of Bashkortostan

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Annotation¹

Knowledge about long term snow cover characteristics within a hydrological basin is essential information for regional and local authorities regarding water availability and flood hazard prediction. Population, economy and environment in the Republic of Bashkortostan (Russia) are strongly affected by regular spring floods. Stronger snowmelt due to steep temperature increase or due to higher snow deposition in the winter period cause local inundations in the Republic of Bashkortostan. In this study we analyze daily snow cover extent data for Volga sub-catchments on the territory of the Republic of Bashkortostan and the influence of snow cover extent on periodic occurring spring floods at four different hydrostations. The snow cover extents and snow cover characteristics were derived from daily MODIS data with a spatial resolution of 500 meters. Parameters such as early and late season snow cover duration and its deviation from long-term mean were processed and calculated for the study region. Additionally, a binary logistic regression function was performed to reveal the quantitative impact and relation between snow

cover extent and local spring floods. The results indicate strong correlation between the rate of snowmelt and occurred spring floods which proof the reliability of moderate spatial resolution remote sensing data towards local-scale flood events. It demonstrates that daily snow cover data with moderate resolution can be used to understand local spring floods.

1. Introduction

Spring floods due to snow melting are periodic natural events occurring all over the world in snow affected regions. The amount of water being stored as snow during the winter is a crucial parameter for water availability and flood hazards. Start, duration and pace of snow cover melting are also critical variables and determine spring floods especially in high latitude regions (Yang, 2003) and thus are fundamental for the hydrologic cycle (Tekeli et al., 2005). Additionally, regions affected by changing climate, changing environmental conditions and human interaction can become more vulnerable towards spring floods caused by snowmelt. The timing and magnitude of snowmelt as well as snow covered areas are the dominating factors for spring floods next to soil moisture and basin characteristics. There are many well established models and approaches for flood monitoring and flood forecasting. Most models predicting water level and inundation are based on hydraulic modeling, hydrologic modelling, remote sensing application or geographic

information systems, or a combination of those components. Meteorological data and weather information are essential elements of river flood modelling. However, regional expert knowledge is required in order to create a model reflecting the reality due to local specifications and different reasons for floods e.g. ice, snowmelt and heavy rain (Merkuryeva et al., 2015). As Immerzeel et al. (2009) stated, remote sensing observations may also be used for precipitation estimation, if the appropriate satellites are involved. For snow cover detection, MODIS products or Synthetic Aperture Radar systems tend to predominate as remote sensing sources (Nagler et al., 2008; Tekeli et al., 2005). Publications of Schreider et al. (1997), Kuchment and Gelfan (1996), Bathurst et al. (2011), Adamowski (2008), Roy et al. (2010) provide valuable information about runoff modelling for snow-affected catchments. On the other side, time-series of optical medium resolution remote sensing data have been exploited for a range of different application, e.g. land cover, land use classifications, inland water dynamics, vegetation dynamics or temperature variations (Eisfelder et al., 2014; Gessner et al., 2013; Jönsson and Eklundh, 2004; Kuenzer et al., 2015; Leinenkugel et al., 2013; Verbesselt et al., 2010).

The objectives of this study are twofold. First, we analyze snow cover extents and snow cover characteristics of relevant hydrological sub-catchments on the territory of the Republic of Bashkortostan. A time-series of 15 years of MODIS data from September 2000 until August 2015 will reveal the most recent snow cover development for the study area which is critical for many local authorities. We use the improved snow cover product, the Global SnowPack (Dietz et al., 2015) which provides cloud- and gap-free information of snow coverage on a daily basis. The Global SnowPack is based on MODIS Snow Cover Product (NSIDC, 2013), whereas clouds, data gaps and possible misclassifications are removed with the algorithm introduced by Dietz (2013). Secondly, we demonstrate the dependency between snow cover extent and occurring spring floods together with available ancillary meteorological and hydrological data. Based on spatio-temporal information of snow cover area (SCA) the impact on spring floods occurring at four different hydrostations is shown. For this purpose we used a binary

logistic regression function to proof statistic correlation and impact of snow cover extent on spring floods. The Republic of Bashkortostan (RB) was the focus region within a pilot project between Russian and German Remote Sensing institutes (UBA, 2014).

2. Study Area

The Republic of Bashkortostan is located in the West of the Ural Mountains on the territory of Russia (approximately between 51-57°N Latitude; 53°-60°E Longitude). With an area of 142.947 km² it covers several hydrological Volga-River sub-basins and a part of the Ural-River basin in the South-East. The Volga sub-catchments cover the mayor part of the study area especially the highly populated and economically developed areas around the main cities (Fig. 1). The Republic of Bashkortostan has approximately 4 Mio. Inhabitants and is considered as one of economically very important regions in Russia, due to its mineral resources, petroleum occurrence, chemical industry and thus well-developed infrastructure. However, the economic and industrial development has also caused severe environmental changes such as alterations of river regimes and land cover changes.

The study region has always been affected by heavy spring floods along the River Belaya (is divided in Belaya 1, 2 sub-catchments) and River Doma (Doma sub-catchment). Snow cover characteristics are affected by several factors. Temperature and precipitation are most important variables determining amount, duration, start, and melt of snow cover. Besides, the more static variables land cover type and topography additionally affect snow cover characteristics. The continental climate dominates the study area which results in high temperatures during summer (max. 30°C) and extremely low temperatures during the winter season (min. -15°C). Surface temperature is a limiting factor regarding snow cover persistence. Only while temperature stays below freezing point an accumulation of snow on the surface is possible which is true from mid of November until mid of March within the RB. The hydrological catchments in the RB obtain most of their inflow from Ural Mountainous especially during the spring period when snowmelt starts. Therefore, the runoff during spring months is dominated by snowmelt.

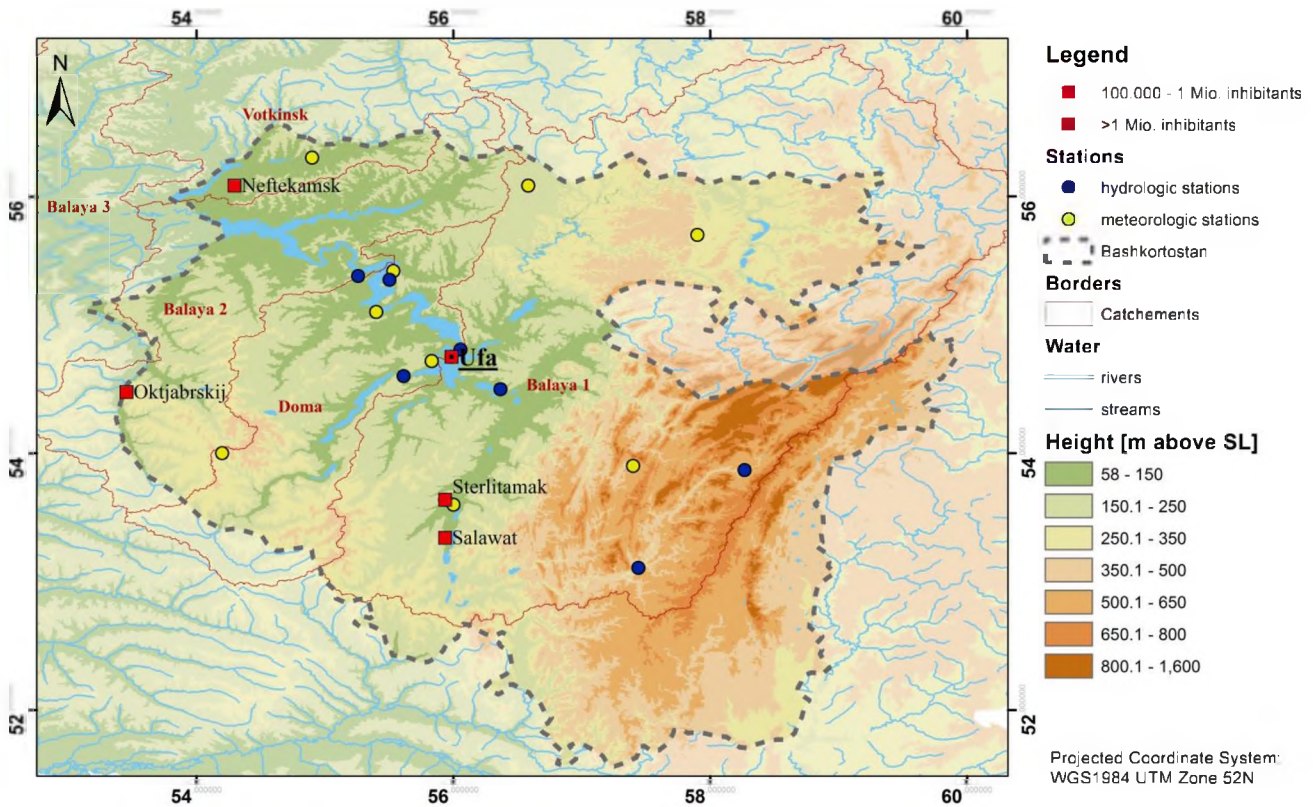


Fig. 1. Study region, Republic of Bashkortostan and its main river catchments (Volga sub-catchments)

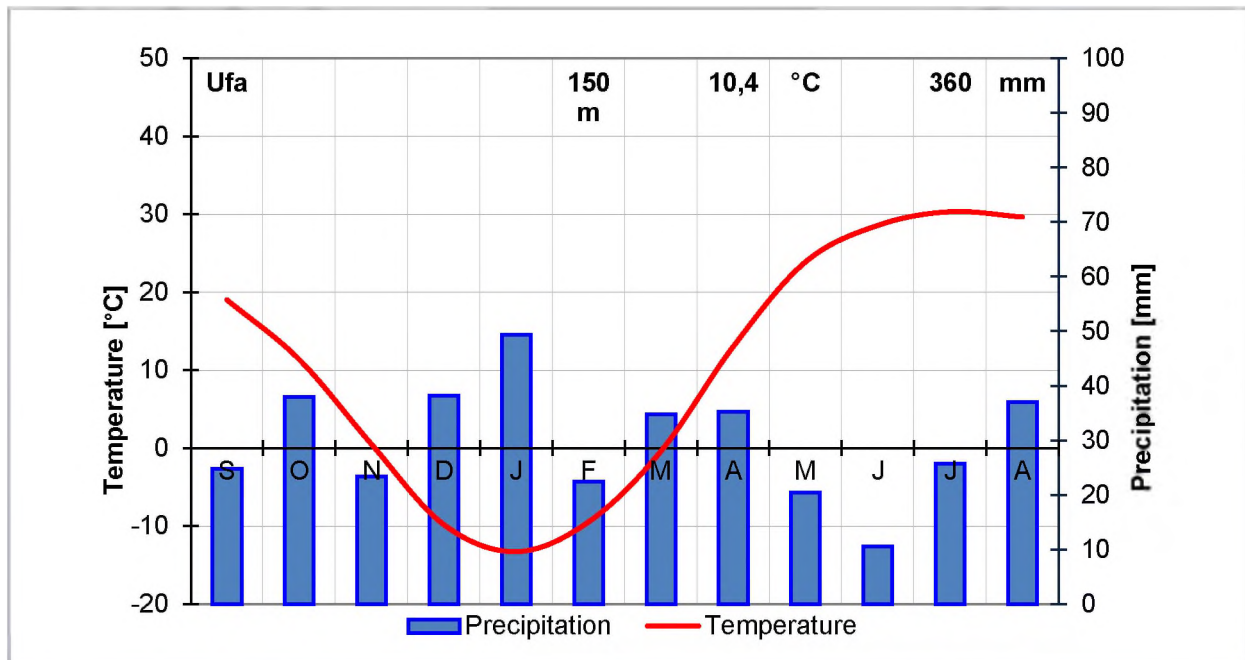


Fig. 2. Climate diagram for the city Ufa (150m above sea level).

3. Materials

1. Remote Sensing Data

Remote sensing data has been used for snow cover detection since the early 1960s. Meanwhile, many new

sensors and snow mapping methods have been established and the development still continues. Review articles summarizing available techniques to identify extent, status, depth, and water content of snow have been published in the past (Amlin, 2008; Dietz et al., 2012; Hall and Martinec, 1985; König et al., 2001;

Solberg et al., 2006). In this study we rely on the datasets derived from both MODIS sensors on board of sun-synchronous satellites Terra and Aqua. The data is available since February 2000 from Terra satellite and

August 2002 from Aqua satellite creating a 15+ years continuous time series of diurnal data. Key parameters of MODIS sensor are summarized in.

Table 1: Technique details for MODIS sensor on board of Terra and Aqua satellites

Satellite / Sensor	Operational since / until	Spectral bands	Spatial Resolution	Swath Width	Data acquisition
Terra & Aqua / MODIS	2000 & 2002 / present	36 bands: 0.62 μ m-4.38 μ m	bands 1-2: 250m; bands 3-7: 500m; bands 8-36: 1000m	2330km	2 per day

The National Snow and Ice Data Center (NSIDC) provides daily snow cover products MOD10A1 (from Terra) and MYD10A1 (from Aqua) which are based on automatic normalized difference snow index (NDSI) algorithm to distinguish between snow cover, snow free land and clouds (NSIDC, 2013). It uses the reflectance of visual and infra-red radiation for both Terra and Aqua MODIS data to calculate the Normalized Difference Snow Index NDSI (Equation 1).

Equation 1: $NDSI = (b4 - b6) / (b4 + b6)$, where b4 and b6 refer to MODIS band 4 (0.54–0.56 μ m) and band 6 (1.62–1.65 μ m), respectively (Hall et al., 2002)

Band-6 for Aqua was replaced by band-7 since band-6 on was defect. This step was necessary to improve the accuracy of Aqua product and is acceptable since band-7 correlates highly with band-6 over land (Riggs and Hall, 2004). The NDSI enables the discrimination between snow and snow free land by exploiting typical spectral characteristics of snow. Namely, snow features high reflection in the visible part and drops near to zero in the infra-red spectra. The snowmap algorithm which is used by the NSIDC applies different tests and thresholds to detect snow cover on daily basis (especially to prevent from misclassification over water bodies and forested areas).

In this study we use the MOD10A1 and MYD10A1 snow cover products to further improve the accuracy and generate a cloud free dataset. The study region is completely covered by only two MODIS tiles (h20v03, h21v03). Therefore, we acquired a total amount of 21900 datasets to enable the analysis over available time period 2000-2015. The thematic MOD10A1 and MYD10A1 products contain information for different classes such as snow cover, snow free land, sea ice and water based on static water mask and clouds. The accuracy of 93% (Hall and Riggs, 2007) of this product has been confirmed by independent studies for different regions (Huang et al., 2011; Maurer et al., 2003; Parajka and Blöschl, 2006; Simic et al., 2004). However, this is only true for cloud free and clear sky pixels.

Furthermore, several Landsat images were downloaded from U.S. Geological Survey (USGS) to allow an accuracy assessment and inter-comparison for the region of interest. The use of high resolution data such as Landsat is a common technique for validation of medium resolution land cover products (Carroll et al., 2008; Hall

and Riggs, 2007; Klein et al., 2015; Kuenzer et al., 2015). The spatial resolution of 30m provides a good source for

validating medium resolution snow cover products. However, mixed pixels may still cause uncertainties and errors especially in transition zones to snow free regions.

2. Meteorological and hydrological data

Daily mean temperature and sum precipitation measurements for the period of 2000-2015 were acquired for several meteorological stations from Weather and Climate (2014) website. The meteorological stations are marked with yellow color in Fig. 1. Additionally, river level measurements from different hydrological stations along the rivers Belaya-1, Belaya-2 and Doma were provided by the USATU and Ministry of Ecology of the Republic of Bashkortostan for the years 2000 until 2010 (compare blue marks for hydrostations in Fig. 1). The river level data were very inconsistent considering covered time span and annual repeatability. Nevertheless, several spring floods on different stations are documented. For the statistical analysis we used the river levels from Andreevka, Bochkaryovka, Ochlebino and Shaksha stations for which river level measurements during spring flood period were available for each year between 2000 and 2010. Generally, the first step in order to combine remote sensing data and meteorological data is to interpolate and adjust the data in an appropriate way, as the data sources' scales differ temporally and spatially. For example, remote sensing observations are made in irregular time intervals, while meteorological data are usually collected at regular intervals and that has to be compensated (Nagler et al., 2008). In our case, this step of pre-processing was not necessary because the data material fitted temporal time resolution.

4. Methods

1. Snow cover characteristics

The biggest challenge in using optical remote sensing data for snow cover detection is the cloud coverage. For example in Central Asia there were approximately 200 cloud covered days per year around mountainous regions which make a direct detection from optical datasets impossible (Dietz, 2013). Therefore, a stepwise routine for cloud interpolation was developed to produce a cloud free time series of snow covered area. The applied approach in this study for the region of Bashkortostan

was developed by Dietz (2013) in the region of Central Asia. In this paper we summarize the most important steps to allow a better understanding of the methodology. For more detail description we refer to cited literature.

The MOD10A1 and MYD10A1 products acquired from NDSI were reprocessed regarding snow and cloud misclassification and interpolated and by using the algorithm described in (Dietz et al., 2014; Dietz, 2013). The improvements focus on a better differentiation between clouds and snow by using the information $\sum_{i=0}^n (Si)$ of both satellites, ancillary digital terrain model (DTM) and the availability of entire time-series of data. After application of all steps we received a dataset of snow cover which has gaps because of the applied combination of two satellites and interpolation for cloud covered days. The cloud-free time-series of snow cover duration was available for September 2000 until August 2015 and thus covers 16 hydrological years (start of hydrological year is set to 1st September and the end to 30th August of the following year). Cloud free binary snow cover layer with diurnal temporal resolution are finally the basis for the calculation of further snow cover parameters such as *snow cover duration* (SCD), *early season snow cover duration* (SCD_{ES}), and *late season snow cover duration* (SCD_{LS}). The SCD, SCD_{ES}, and SCD_{LS} are calculated according to Equation 2, 3, and 4.

Equation 2:

where n is the number of days for the respective year (usually 365; 366 for leap years), and Si is the binary snow cover information (1 = snow, 0 = snow free) for day i .

Equation 3: $SCD_{ES} = F_d - SCD_{bF_d}$.

Equation 4: $SCD_{LS} = F_d + SCD_{aF_d}$.

where F_d is a fixed date (in this case January 15th). Thus SCD_{bF_d} and SCD_{aF_d} refer to SCD before F_d and SCD after the fixed date.

The parameter SCD provides the information about the total number of snow covered days for a defined temporal interval. In this study we refer to hydrological years which span from beginning of September and last until end of August of consecutive year. The parameters SCD_{ES} and SCD_{LS} are based on the number of days before and after a fixed date which was set to 15th January. The 15th January is considered to be the date with the maximum areal snow cover extent in our study region. Intermediate snow cover events are not considered by this approach. Therefore, the SCD_{ES} should be considered as early season start and the SCD_{LS} as the last snow covered period.

The MOD10A1/MYD10A1 daily snow cover product has been validated by various researchers during several studies throughout the world as already stated in Section 3.1. The clear-sky accuracy was confirmed to reach ~93% (Hall and Riggs, 2007). Validation of presented snow cover product was performed and is presented by Dietz et al. (2015).

2. Statistical Analysis

There are many sophisticated hydrological models e.g. such as Snowmelt Runoff Model (SRM) presented by Martinec et al. (2008). These models require a range of different input datasets to be able to calculate and predict runoff of a river. Due to a lack of free accessible comprehensive datasets for the territory of RB, we decided to use a binary logistic regression function to demonstrate the influence of snow cover parameters on river level and possible spring flooding. We applied the binary logistic regression (BLR) analysis by using available hydrological and meteorological datasets as well as snow cover metrics which were derived within this study. The BLR aims to discriminate between two groups, describe their differences and to predict group membership of a dependent variable (Mood, 2010). In the described case, we consider flood and no flood as two separated groups. This is reflected in river levels at each hydrological station as our dependent variable. Thus, the historical records of water level from hydrological station can be discriminated in these two groups. One of the aims of the BLR is to determine the value of independent variables and how strong it influences the dependent variable (Baltes-Götz, 2008; Bewick et al., 2005; Mood, 2010). The BLR differs from linear regression mainly that no metric variables are determine but binary group membership. However, it has one main advantage, that the change of independent variable is not always coupled with a change of dependent variable. Therefore, independent variables can influence the dependent variable differently in its strength and direction.

5. Results and Discussion

1. Snow cover characteristics in Volga sub-catchments for the Republic of Bashkortostan

Figure 3 (left) illustrates the mean evolution of snow coverage over the Volga sub-catchments on the territory of RB. The fraction for all Volga sub-catchments within the study area show similar annual characteristics with almost 100% snow coverage during the winter months, a steady rise in snow coverage from late September and steady decrease from late March. Figure 3 (right) also visualizes temporal development and daily snow coverage deviations compared to long term average (here hydrological years from 2000/2001 till 2014/2015).

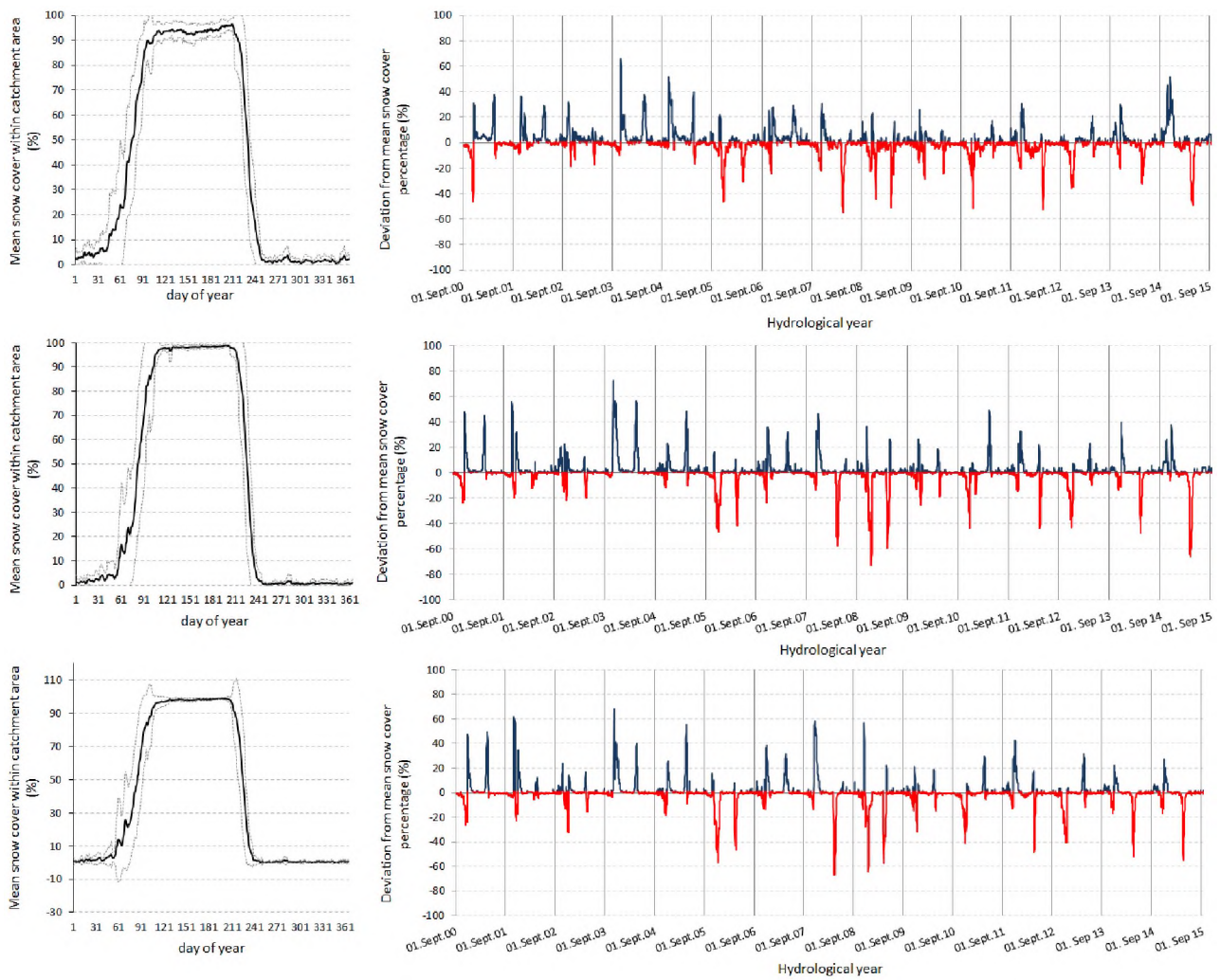


Fig. 3. Mean snow coverage and +/- standard deviation (left). Deviation from mean snow cover area for each day (right). Blue color indicates larger snow covered areas and red color indicates smaller snow covered areas compared to mean (2000-2015). Catchments from top to bottom: Belaya1, Belaya2, Doma.

Beside the temporal information and knowledge which year experienced quantitatively longer or shorter time periods of snow coverage, the spatial variability has to be taken into account. 4, 5, 6 and 7 present SCD, deviation from mean SCD, deviation from mean SCD_{ES} and deviation from mean SCD_{LS} for selected exemplary years. Analyzing this spatial datasets one can extract valuable information on spatial and temporal variability between the years. We shortly discuss the main features of exemplary hydrological years (all other years are available on request). The deviation from long term mean SCD reveals outlined years compared to the 16-year-average snow cover duration. It illustrates areas which feature longer SCD and areas which feature shorter SCD. The winter seasons 2001/2002, 2002/2003 and 2004/2005 show longer periods of snow covered area

especially in the mountainous region and in the Ural Mountains. In general the mountainous region and the Ural Mountains are pronounced by longest SCD compared to the lower lands. The seasons 2010/2011 and 2012/2013 were the winters with least snow covered area in the observed time period. The start of snow season was up to 40 days earlier in the snow-rich winters 2002/2003, 2004/2005. On the contrary, the winter seasons with shorter snow cover duration feature a delay of up to 20 days. Later start of the melting process was observed in the seasons 2000/2001, 2002/2003, 2004/2005. In the case of later start of melting process a more extreme and pronounced temperature raise might occur. One of the consequences is mirrored in the examples of spring floods presented in section 5.3.

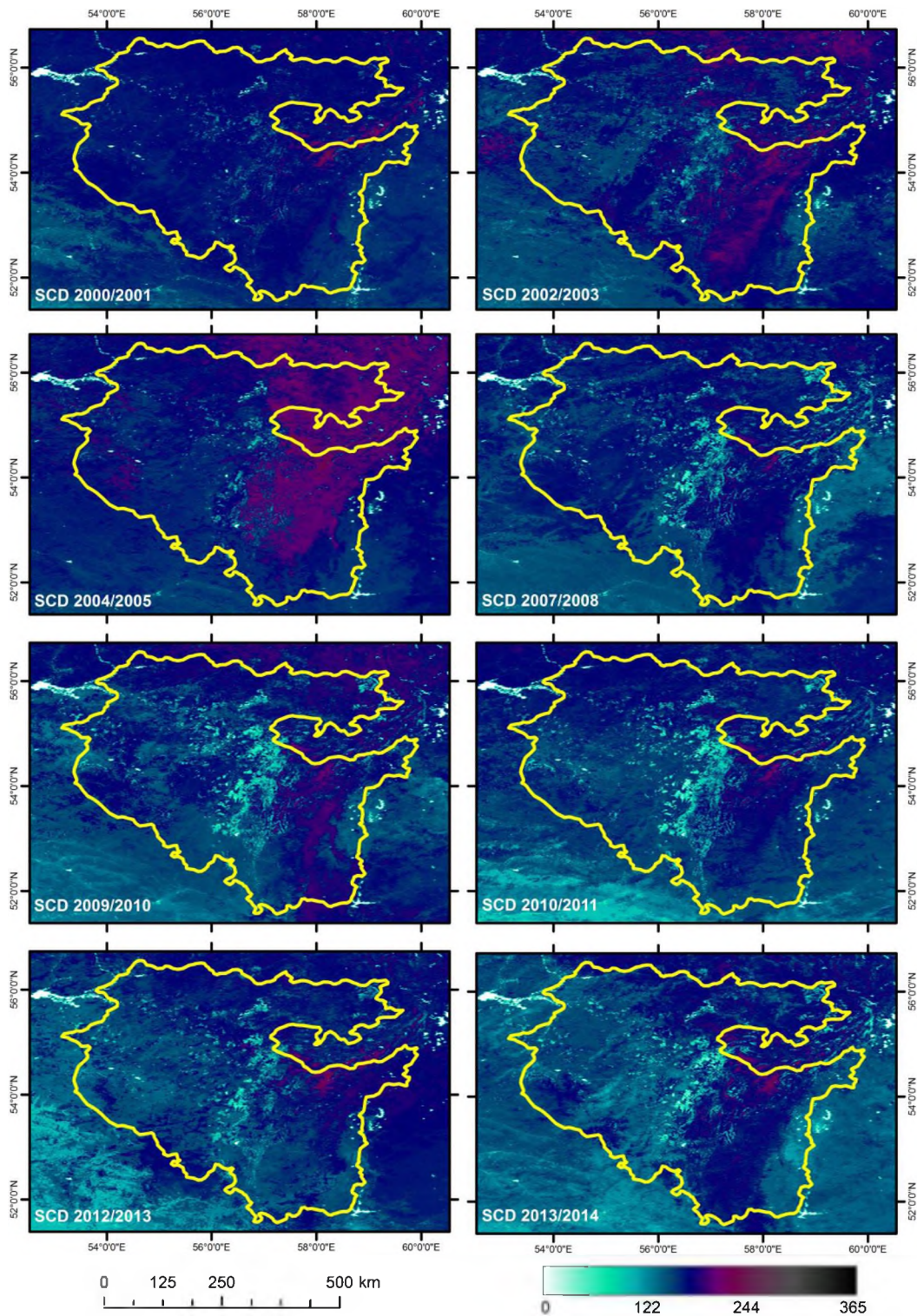


Fig. 4. Spatial variability of SCD for exemplary years for the region of RB

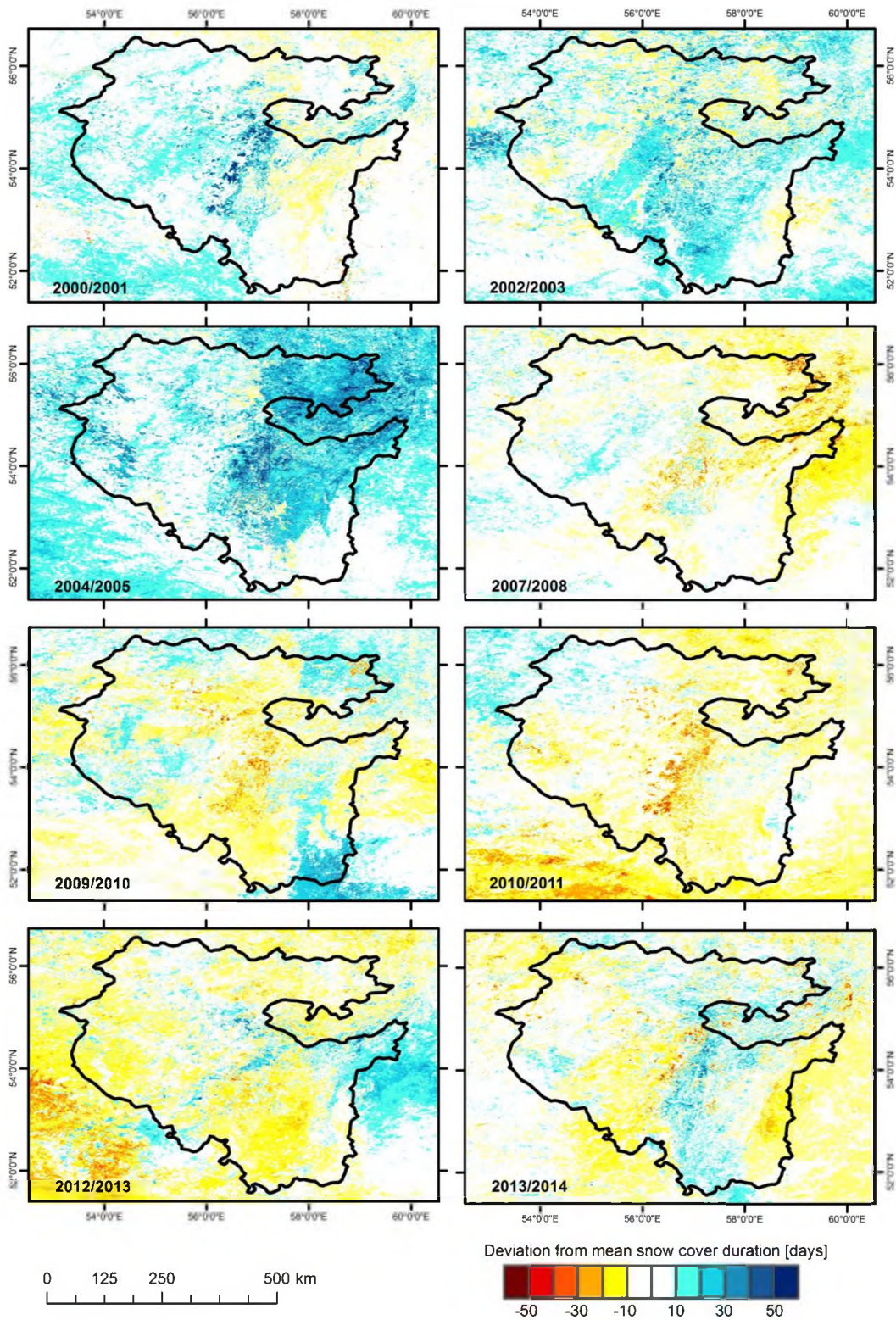


Fig. 5. Deviation from mean SCD for exemplary years for the region of RB

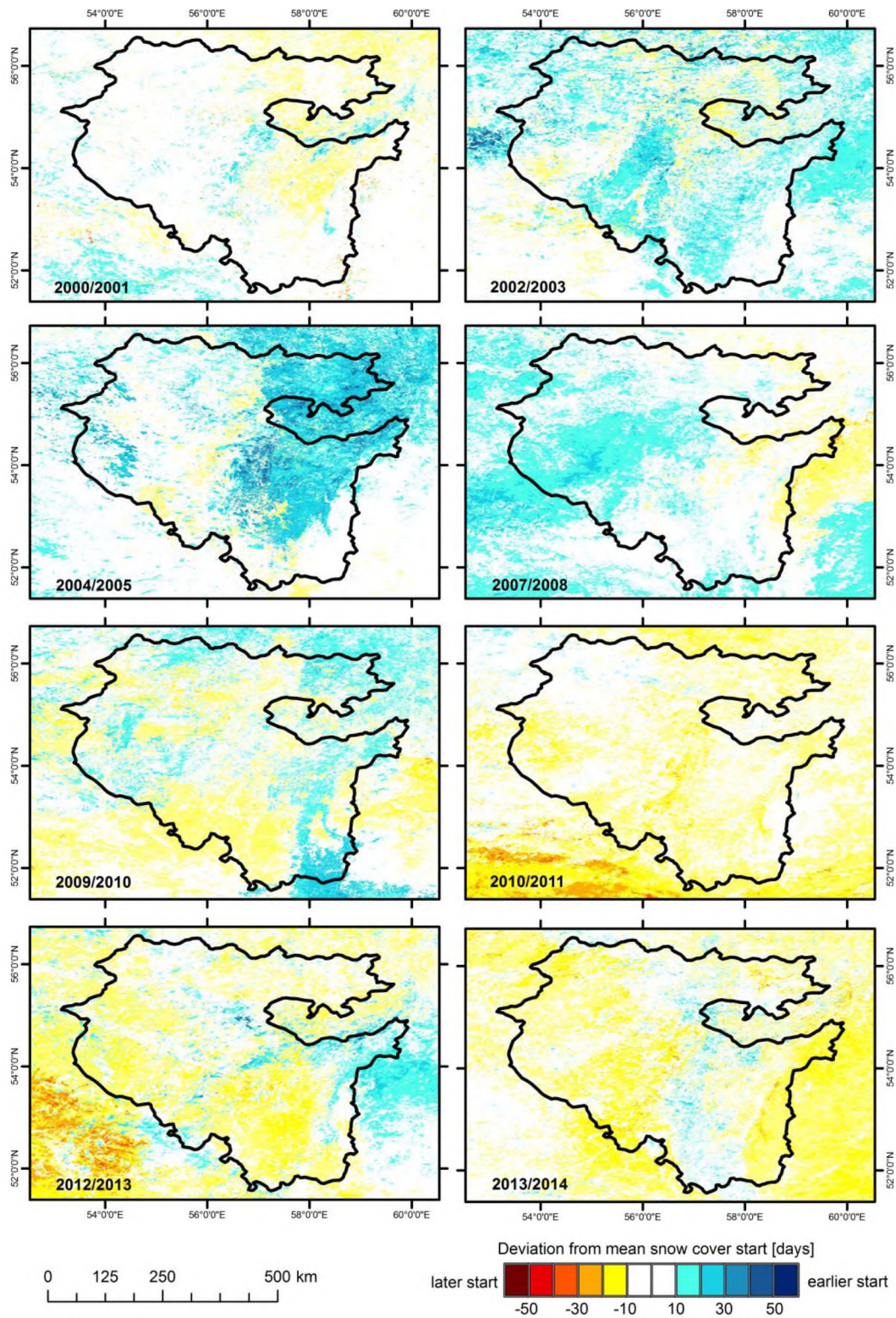


Fig. 6. Deviation from mean SCD_{ES} for the region of RB.

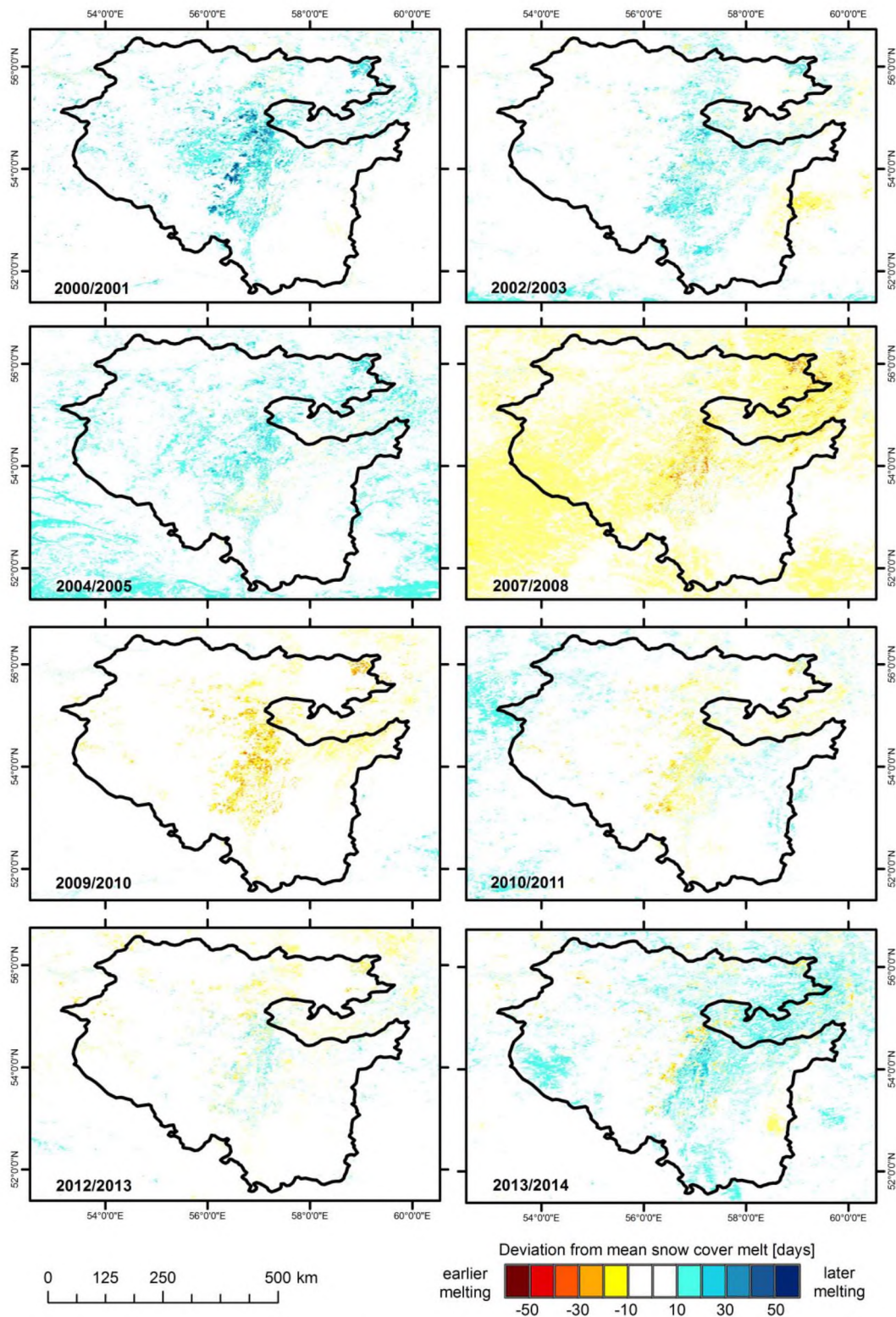


Fig. 7. Deviation from mean SCD_{LS} for the region of RB

3. Binary logistic regression results

The following section presents, the results gained through the binary logistic regression, its quality and meaningfulness, its ability to predict the corresponding

group (flood or no flood) and therefore its capacity to interpret certain value combinations of the independent

variables as an indicator of a possible flood event. The binary regression function was successfully applied in different other disciplines (Howard et al., 2003; Mair and

melting on spring floods and the ability of snow cover parameters to describe this relationship.

Clear correlation is visible between rising temperature (coefficient of determination $R^2=0.81$ for the time period of increasing water level), snowmelt and rising river level. In few cases precipitation is also contributing to higher river level and measured spring floods. In case of Andreevka hydrostation, one can easily proof that snow cover melts in a very short period of time after the temperature rises above 0°C for the first time right at the start of spring. Especially when temperature reaches about 10°C the snowmelt increases rapidly. The sudden

amount of melt water reaching Andreevka hydrostation usually results in an increased water-level, which normally exceeds 508 cm (flood water border). Interestingly, in years with a comparatively slow warming in spring, like 2006, a slower snowmelt can be assumed, so that the flood water border is not succeeded at any time. Generally, the water-level decreases again, after 70% of snow cover has melted, and the water-level uses to decline under the flood water border again. As there is not much precipitation in the corresponding sub-catchment, the precipitation does not influence the water-level significantly (Figure 9).

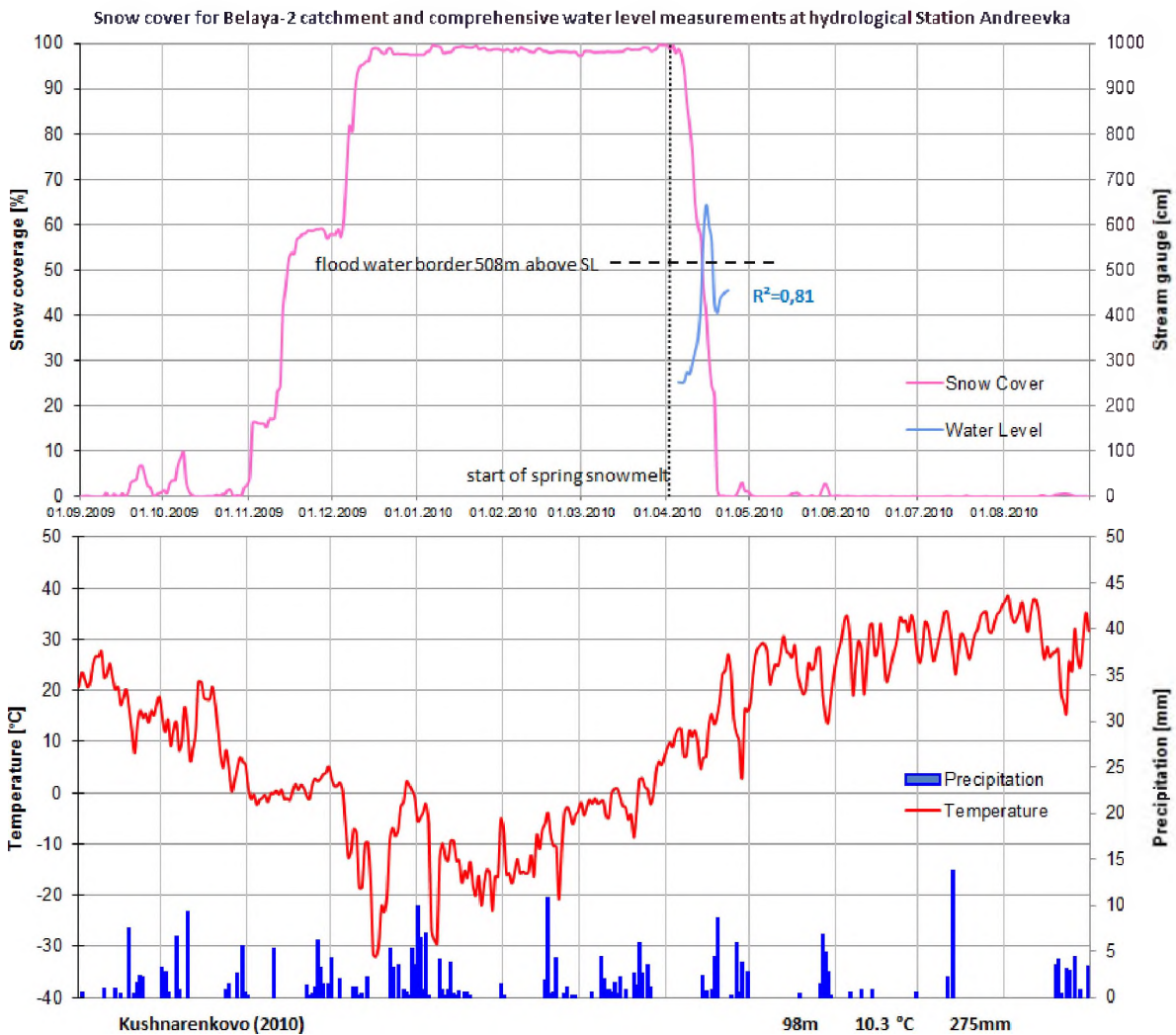


Fig. 9. Snow cover extent within Belaya-2 catchment and river level measurements at Andreevka hydrostation 2010 (above). Daily average temperature and daily sum precipitation at the closest meteorostation Kushnarenkovo (below). Coefficient of determination R^2 for snow cover extent and river level during the rising water level period.

The hydrostation of Shaksha is situated next to the city of Ufa and is influenced by several river regimes, which converge in city of Ufa. Therefore, the measurements at Shaksha are dependent on the characteristics of several sub-catchments, especially Belaya-1 and Doma. Concentrating on Belayaa-1 catchment it is obvious that snowmelt occurred more slowly compared to Belayaa-2 catchment (possible reasons are different sun intensities, underground conditions, and snow density and

consistence, rain or wind conditions). As the flood water border is around 900cm and comparatively high, flooding events rarely occurred at Shaksha station (2001 and 2007 for available river level data 2001-2010). Those events mainly interact with a sudden snowmelt at Belayaa-1 and higher precipitation events being responsible for the water-level peaks. The coefficient of determination between snow cover extent and rising river level for the spring flood in 2007 was 0.96.

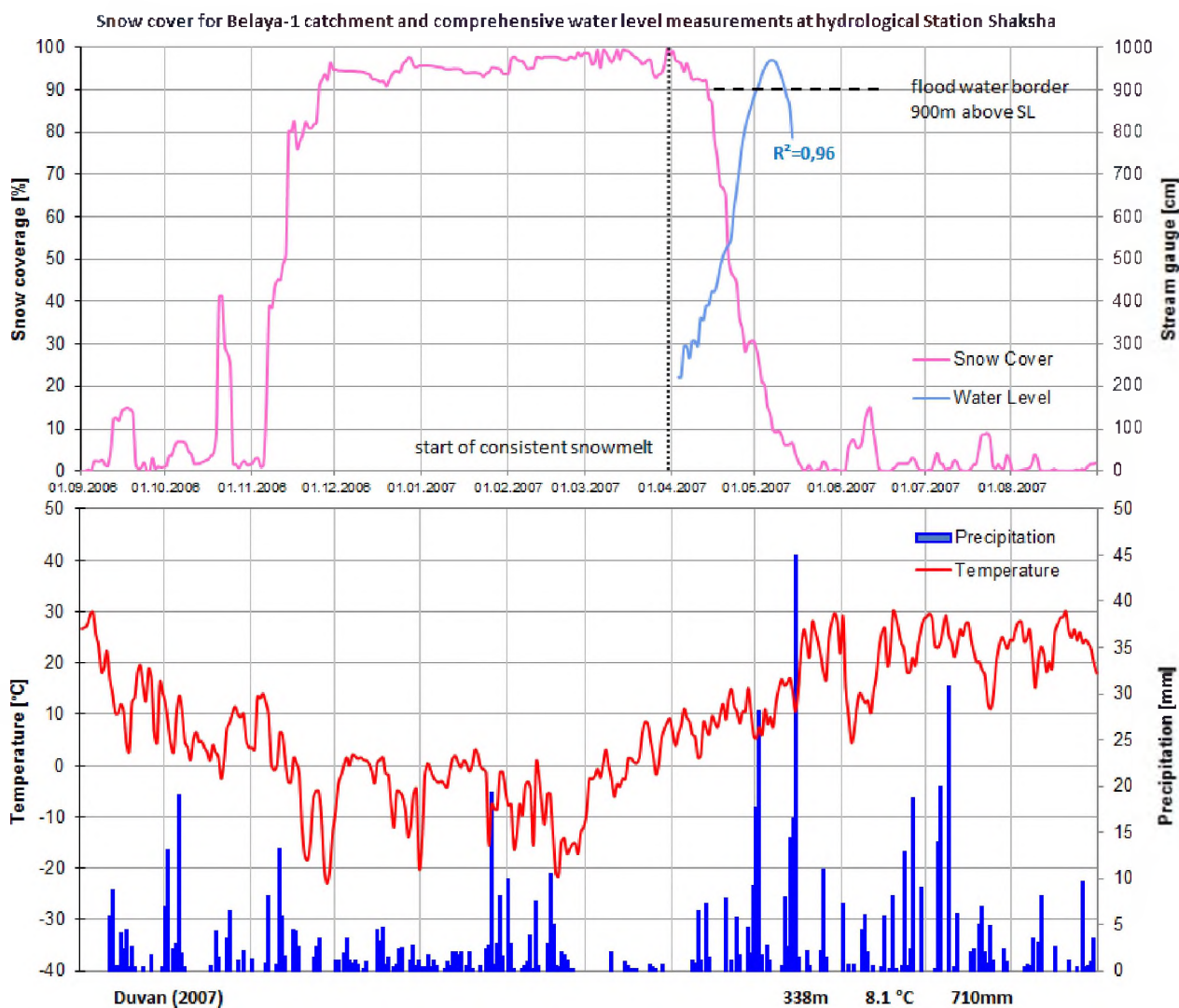


Fig. 10. Snow cover extent within Belayaa-1 catchment and river level measurements at Shaksha hydrostation 2007 (above). Daily average temperature and daily sum precipitation at the closest meteostation Duvan (below). Coefficient of determination R^2 for snow cover extent and river level during the rising water level period.

The Bochkaryovka hydrostation within Doma catchment it is more difficult to interpret. For the available hydrologic years 2001-2010 the river level exceeded the flood water border of 710cm above sea level in 2001, 2003, 2005 and 2009. It seems to be evident that the melt water reaches Bochkaryovka hydrostation few days after

the snowmelt start. Statistically analyzed, the local water level usually rises between four and ten days after snow melting. The influence of precipitation is very marginal in this case, while the effect of temperature varies over the considered period of time. Unlike Belaya-1 catchment, the snowmelt proceeds much faster within Doma catchment.

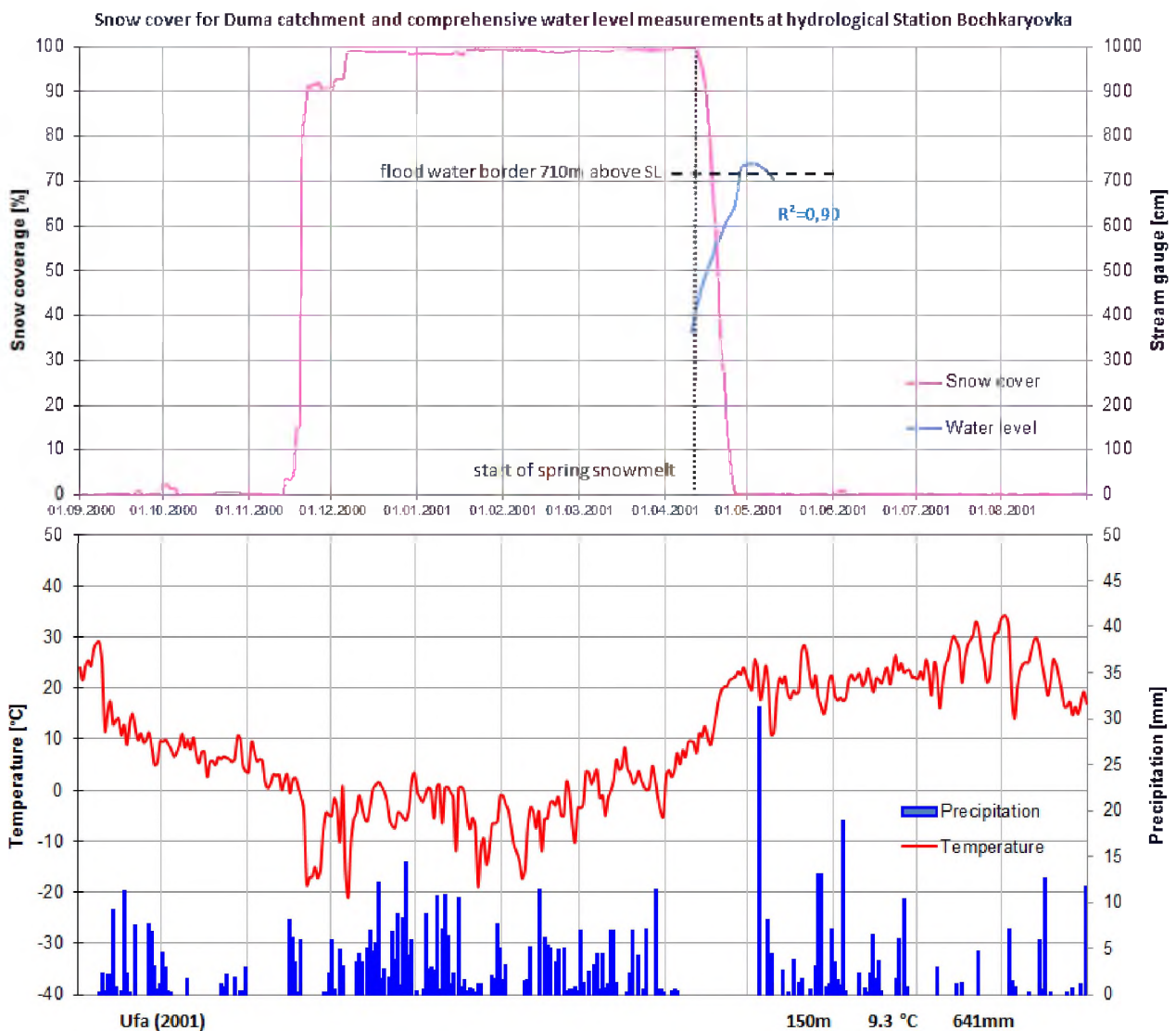


Fig. 11. Snow cover extent within Doma catchment and river level measurements at Bochkaryovka hydrostation 2001. Daily average temperature and daily sum precipitation at the closest meteorostation Ufa (below). Coefficient of determination R^2 for snow cover extent and river level during the rising water level period.

At Ochlebino hydrologic station, again a significant correlation between snow cover melting and water level is evident ($R^2=0.87$). The snowmelt in Belayaa-1 catchment generally takes off when the temperature reaches 10°

Celsius in spring for the first time and the melting process lasts longer compared to other catchments. Only in years with a strong temperature rise in spring and therefore a faster melting of snow cover, the flood water border of 860cm gets exceeded. During the time period from 2001 to 2010, spring floods occurred in 2005 and 2007.

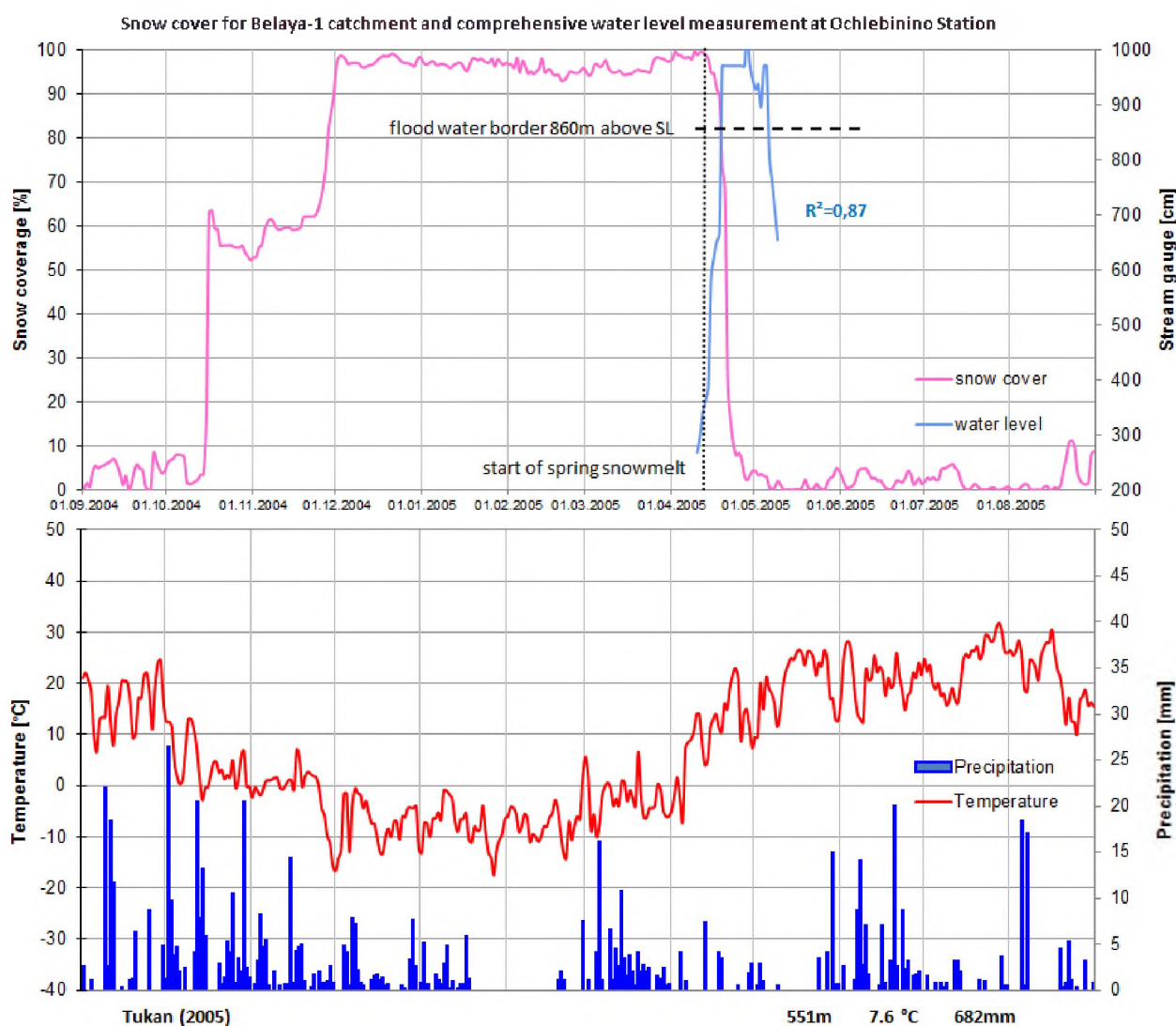


Fig. 12. Snow cover extent within Belayaa-1 catchment and river level measurements at Ochlebinino hydrostation 2005. Daily average temperature and daily sum precipitation at the closest meteostation Tukan (below). Coefficient of determination R^2 for snow cover extent and river level during the rising water level period.

Although lots of well-developed, globally useable hydrologic models exist, a spatially adapted hydrologic model has been created. Only spatially detailed models are able to scale the necessary parameters in an appropriate way, which can be seen as advantage (Chen et al., 2011). In fact, a spatially adapted model is able to work with less parameter as more general models, as for example land cover or soil information is not needed specifically and the model is automatically adapted to those circumstances. Knowledge about the accurate spatial distribution of snow cover at any time could be an impact instead, so that arrival time and amount of melt water can be better estimated (Luce et al., 1998). Snow distribution is usually only considered in very small scaled analysis and could be interpreted as suggestion for future work.

The general aspect of giving snow cover characteristics a high weight in hydrologic modeling seems to be justified, as they might function as most important hydrologic processes in high altitude regions. Although the density of

hydrographic and meteorological stations in Bashkortostan is not ideal, a useable hydrographic model by means of a binary logistic regression could be performed. Specific methods to deal with sparse data material, especially air temperature data, might even improve the model (compare for example the approach of Yang et al. 2014). Finally, it can be stated, that snow cover information derived by methods of remote sensing from moderate resolution sensor is useful for creating a hydrologic application, which is able to be used as a warning system for possible flooding and can therefore prevent the settlements from greater damage.

In our performed binary logistic regression, we discovered that the precipitation only had a marginal influence in deciding group membership (flood or no flood) because of minor precipitation amounts during the spring flood occurrence. Further investigation should focus to rain-on-snow events (as precipitation is usually realized in form of rain falling on snow in spring months). It has to be stated that precipitation rarely

occurred during snow melting period; at least no heavy rain events were observed.

Generally, rain-on-snow is a typical event in mountainous regions causing high water-levels and plays a decisive role in hydrology (Singh et al., 1997). Events of rain-on-snow tend to result in extreme floods and many large river floods in the past were a consequence of rain-on-snow events. Even avalanches and landslides often occur with rain-on-snow events. One main reason for this phenomenon is that the speed of water movement gets increased by heavy rainfalls, as vertical preferential paths are developed within the snowpack, which allow faster moving water. In case of natural snow melting, the whole water movement proceeds much slower, whereby the risk of a flood gets limited. Rain-induced melt itself does not play an important role, but rainfalls tend to saturate and condition the snowpack in a way that the runoff process can be performed comparatively fast (Singh et al., 1997; Sui and Koehler, 2001). Therefore it is remarkable that the influence of precipitation is very low and may be explained by the fact that precipitation in spring is kept within a limit at the region of RB. Similar strong linkage between snow cover extent and increased river discharge was observed by Yang et al. (2003) for large Siberian catchments.

6. Conclusion

The purpose of this study was to analyze snow cover characteristics for the area of Republic of Bashkortostan for the time period from 2000 to 2015. Furthermore, we intended to demonstrate a possible hydrological application of snow cover parameters such as snow cover duration (SCD), early season (SCD_{ES}), and late season SCD (SCD_{LS}) which were derived from optical medium resolution remote sensing data. In general, the mountainous range of Ural Mountains is evident through longer SCD compared to the lower lands. The winter seasons 2010/2011 and 2012/2013 experienced least snow covered area in the observed time period. SCD_{ES} was up to 40 days earlier in the snow-rich winters 2002/2003, 2004/2005. On the contrary, the winter seasons with shorter snow cover duration featured a delay of up to 20 days. Later start of melting process mirrored by the variable SCD_{LS} was observed for 2000/2001, 2002/2003 and 2004/2005 seasons.

The second goal was to demonstrate how spring floods depend on snow cover characteristics in the Republic of Bashkortostan. Auxiliary meteorological as well as river level data were used to assess the influence of derived snow cover parameters towards spring floods. Unfortunately, there is still a lack of open access hydrological data in many parts of the world due to different reasons. Nevertheless, the results show strong correlation between snow cover parameters and local-scale springs floods measured as river levels. During the period of rising river levels strong correlations ($R^2 = 0.81, 0.96, 0.90, 0.87$) between increasing water level and decreasing snow cover extent within the corresponding sub-catchment were observed. Despite the fact of poor hydrological data access it was possible to identify a clear

correlation of local scale floods occurred in the Belaya and Doma catchments and large scale snow cover extent. This proves that parameters and products derived from moderate remote sensing data are reliable and can play an important role for local flood assessment. The cloud free snow cover parameters are now available on global scale (Dietz et al., 2015). Especially the influence of beginning snow cover melt period and the melting pace are essential factors for spring floods and can serve as essential information regarding flood prediction. We observed that changes in snow cover extent several days in advance of occurring spring floods were most decisive for rising river levels. The number of days between starting snowmelts and observed spring flood depends on many other environmental parameters such as frozen soil, terrain steepness, land cover type, abrupt temperature raise or precipitation. In future, further research is required in terms of including comprehensive data to derive more clear dependencies between all the variables for individual sub-catchments. Especially, the knowledge about the relation between snow cover extent and associated spring floods at sub-catchment scale based on passed events is valuable. In this way statistical models and regressions based on past measurements can be created and used for accurate early warning by detecting snow coverage and discussed parameters.

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