



Climate and Snow/Glacier Water Resources Changes in central Asia in the last 50 years based on remote sensed and in-situ data

Vladimir Aizen, Elena Aizen, Arzhan Surazakov
University of Idaho, U.S.A., aizen@uidaho.edu

Valeriy Kuzmichenok, IWRH, KAS, Kyrgyzstan, iwp@istc.kg

Siri Jodha Khalsa, NSIDC, U.S.A. sjsk@kryos.colorado.edu

Stanislav Nikitin, Tomsk State University, Russia, santvp@mail.tsu.ru

THE GOAL:

Estimate changes in the half-century of snow- and glacial-covered areas, and glaciers' volume, simulate and predict the dynamics and feedbacks of a half-century of changes in seasonal snow/glaciers water resources and glacier runoff.

RS data: Aerial photos (1943-1990); DEMs resulted from SRTM, 2000; Corona KH-9 (1972-1973), Landsat TM (1982-present), ETM+ (1999-present), ASTER (1999-present); ALOS/PRISM

NOAA AVHRR (1987-1999), MODIS 8-day snow product (2000-present), (MOD12Q1) to get a suite of Land Cover classifications, MODIS Collection 5, MODIS NDVI.

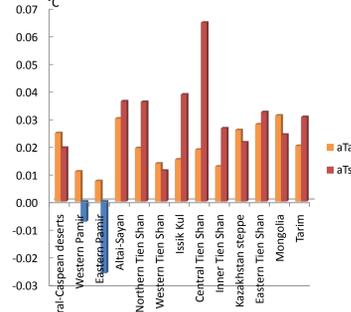
DEM generation: Alpine relief introduces strong geometric distortions. Some stipulation has been applied to accurate DEM development in the process of orthorectification. An unedited version of SRTM 3 arc-second data acquired in the C-band frequency. In areas of rugged terrain, the SRTM data often has void areas due to InSAR technological limitations in mountainous areas. The voids were filled with ASTER DEM generated in the "Leica" Photogrammetry Suite software package (LPS) using ASTER bands 3N and 3B. To estimate the DEM vertical accuracy, we used IcesAT laser altimetry data (GLA14 Global Land Surface Altimetry data, release 28) collected from 2003 to 2007.

KH-9 Hexagon images: 56 KH-9 panchromatic photographs scanned at 14 μ m, 6-9 m nominal ground resolution. Prior to photogrammetric processing, the digitized images were geometrically and radiometrically corrected. Using the reseau grid exposed on the KH-9 frames, we found and rectified significant image distortions with irregular patterns. The image contrast was enhanced both locally (Wallis adaptive filter) and globally (image balancing). KH-9 image orientation was performed in LPS with Ground Controls Points collected from orthorectified Quickbird imagery available in Google Earth™. Google™ kindly granted permission to use Quickbird imagery as a GCP source for this study. 70% endlap and 10-70% sidelap of the KH-9 images enabled a single bundle block adjustment with horizontal errors of 9 m (RMS). The oriented images were orthorectified using the Tien Shan DEM, radiometrically balanced, and assembled in a mosaic on a strip-by-strip basis.

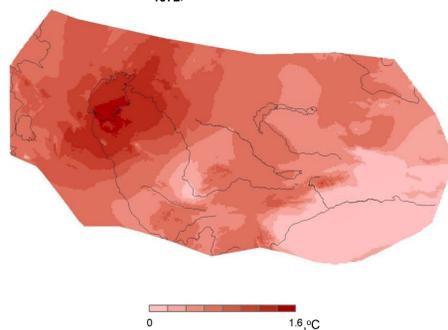
ASTER images processing: 21 ASTER and 27 Landsat ETM+ images acquired from 1999 to 2006. Due to frequent summer snowfalls and heavy cloudiness, some parts of central and eastern Tien Shan required two to four images acquired under different conditions to identify glacier boundaries. The ASTER images were oriented and orthorectified (RMSE 9-15 m) using the Tien Shan DEM, GCPs from KH-9 mosaic. The horizontal accuracy \sim 13m. Four of the Landsat images were orthorectified analogously to the ASTER images and the rest images were acquired already georeferenced (Geocover and L1T products) with errors of 18-35 m.

Surface data from 251 stations over all central Asia. Homogeneous data of air temperature, precipitation and river runoff from 1942 to 2003. Altitudinal range -134 b.s.l. -4,169 m a.s.l. Two period statistical analysis 1942-1972 and 1973-2003 (differences in averages, linear trend, acceleration in changes, differences in standard deviations). Two methods of spatial interpolation (spline and geographically weighted regression).

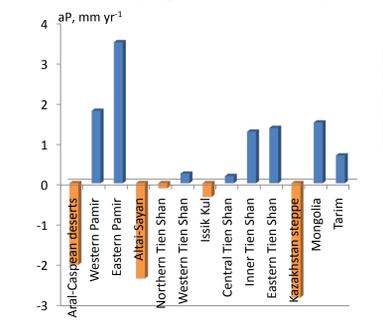
Acceleration of changes annual (aTan) and summer (aTs) air temperatures in central Asia by regions for the last 30 years.



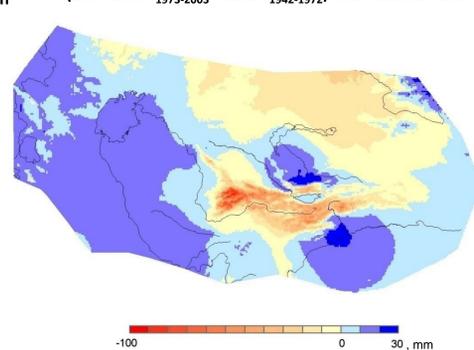
Differences in 30-year averages of summer mean air temperatures ($dT_s = aveT_{s1973-2003} - aveT_{s1942-1972}$) over central Asia



Acceleration of changes annual precipitation in central Asia by regions for the last 30 years.



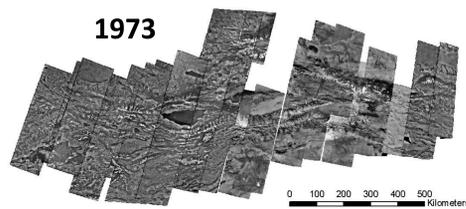
Differences in 30-year averages of annual precipitation ($dPs = avePs_{1973-2003} - avePs_{1942-1972}$) over Central Asia



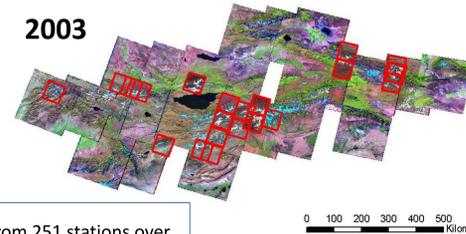
Results: Changes in climate notably accelerated since 1972/73 in Central Asia. Air temperatures increased by 0.5°C all over the Central Asia in the last thirty years (1973-2003) in compare with the previous thirty years (1942-1972). Air temperatures increased significantly both in winter and summer, but mainly in summer (0.024°C yr⁻¹ or 0.72°C for the last 30 years) over the Aral-Caspian deserts and above 2000 m elevations. Precipitation decreased in Central Asian mountains (-100 mm), except the Western Pamir, and Altai mountains. Precipitation also increased over Aral-Caspian prairies and deserts (+27 mm), Northern and Southern Tien Shan foothills, in Taklamakan desert, and over Issik-Kul Lake. For the last 30 years, the total amount of annual precipitation surplus over the central Asia equal 355 km³ compared to previous thirty years. Increase in precipitation over the Issik-Kul Lake and increased glacier melt caused rise of the Issik Kul Lake level. Increased precipitation over Aral-Caspian and Taklamakan deserts decrease frequency of dust storms and mineral loading to atmosphere. During the last twenty years, the duration of snow melt from the date of maximum snow cover to the date of its disappearance reduced by 30 days, equal 138 days in 2007. The seasonal snow covered area in the Tien Shan decreased by 15% (120,000 km²) and there is a tendency for later dates of the maximum snow cover. Snow melts 30 days faster than 20 years ago. In 2003 the total area of the Tien Shan glaciers was 13,276 km². The total glacier area loss from 1973 to 2003 is 7.1%. The largest area loss occurred in the Northern and Western Tien Shan (-12.0-14%). Similar glacier area loss occurred at the Issik Kul Lake basin (-11.0%). The least glacier recession occurred in the Central Tien Shan region, where summer air temperatures increased only by 0.26°C and annual precipitation decreased by 13.4 mm. For the last thirty years (1973-2003) long-term mean runoff on average increased by 2% compared with previous thirty years, while thirty year mean in annual maximum runoff decreased by 5% on average. River runoff increased mainly in the watersheds with large glacierized area and positive difference of glaciation (PDG) (up to 8%), while in the watersheds with mixing and prevailing snow melt the total runoff decreased on 2% in average. Mathematical simulation of the current glacier state and forecast the potential impact of global and regional climate change on the glaciers and glacier river runoff in the Tien Shan estimated that an increase in air temperature of 1°C at Equilibrium Line Altitude (ELA) must be compensated by a 100 mm increase in precipitation at the same altitude to maintain glaciers in their current state. An increase in mean air temperature of 4°C and precipitation by 1.1 times of the current level that is predicted for the 21st century may uplift ELA by 570 m during the 21st century. The number of glaciers, glacier covered area, glacier volume, and glacier runoff are predicted to be 94%, 69%, 75%, and 75% of current values. The maximum glacier runoff may reach as much as 1.25 times current levels while the minimum will likely equal zero. Current glaciers recession, while initially considered as a positive factor that increased the river flow, at the end causes the runoff to decrease.

The central Asian High Mountains (Altai, Tien Shan, Pamir) are a Water Tower for about 100 millions of people living in this region. The central Asia region covered of 12 million km² with mid- latitudinal extend over 5,000 km. The glaciers of central Asia comprise over 3,000 km³ of fresh water. The area of central Asia is one and half times larger than whole territory of the United States. Central Asian mountains are a natural barrier for air masses passing over the deserts and prairies and have great influence on global and regional atmospheric processes and water cycle. Seasonal snow cover and glaciers of central Asia are supplying water and generate river flow vital for the millions of people living downstream and adjacent lowlands. The recent rapid climatic changes and poor planned human activity has been identified as contributing to the central Asia land degradation. Since the middle of 19th century glaciers of central Asia lost approximately 25% of their total area and rate of the glacier recession accelerated particularly from 1970th. Another important source of fresh water is the seasonal snow pack that contributes up to 80% of water in total river runoff in non-glacial basins, but from the 1960th to the present, the depth of seasonal snow pack and its duration decreased, which increases role of glacier melt water in river runoff formation. Apparently, changes in water regime requiring new approaches for regional agriculture planning and further social and economical sustainability of the central Asia oasis's.

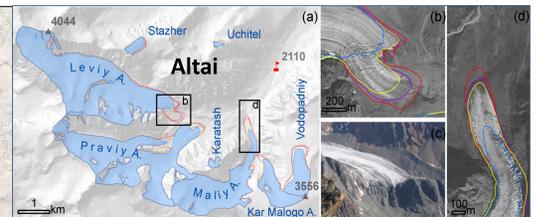
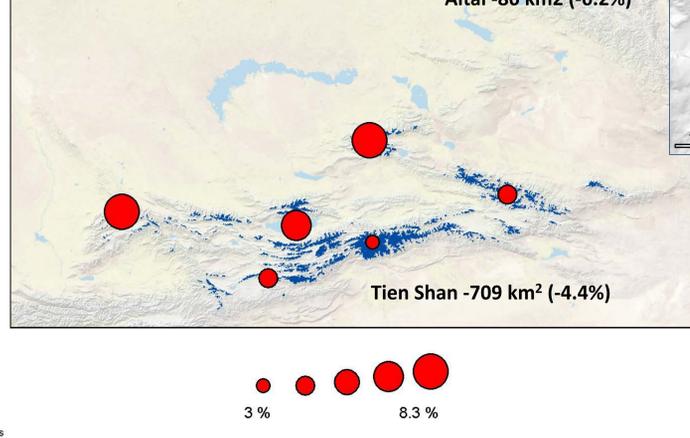
Mosaic of 56 orthorectified KH-9 images



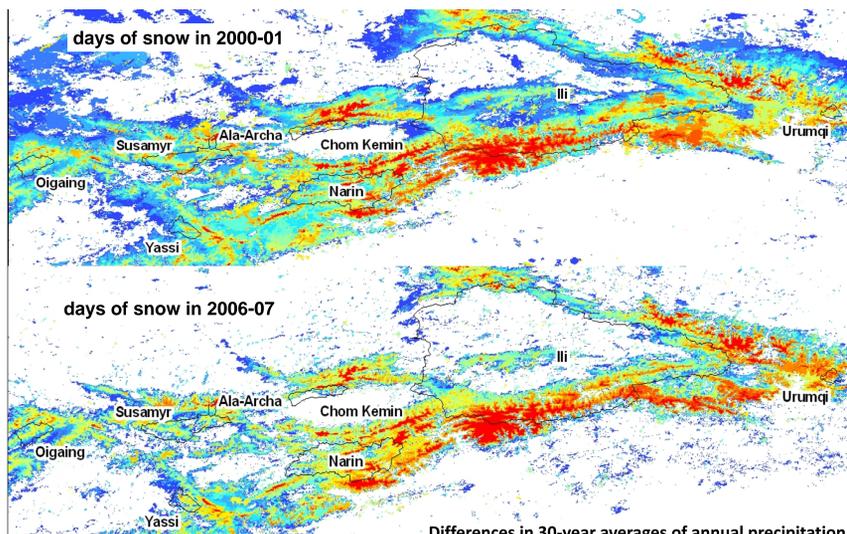
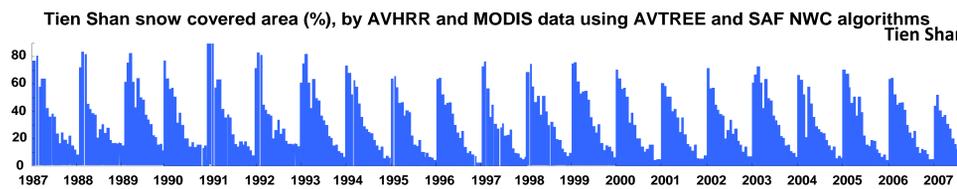
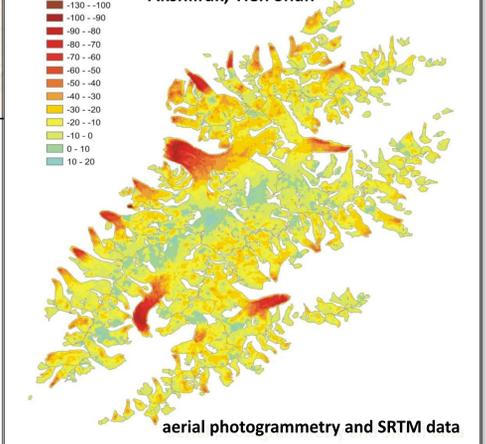
Landsat ETM+ and ASTER images



Glacier area change 1973-2003



Glacier surface degradation 1977-2000 Akshirak, Tien Shan



Modis data processing. To assess the impacts of cloud coverage and to estimate the date of maximum snow depth, we first performed an analysis using fractional snow data from MODIS (Collection 5) and MODSCAG product. The MODIS 8-day product was covered area above the 1000m contour encompassing the entire Tien Shan. This analysis was performed for the winter/late spring, capturing the peak and decay of snow cover. For the large area contained within the 1000 m contour the fraction of pixels that are cloud-obscured for every day in an 8-day period is small, usually less than 5% but occasionally, less than one 8-day period every other year, the value may be 20% or greater. In winter clouds are occur over snow, to avoid misidentification of snow as cloud, we added the cloud fraction to the snow fraction to give a probable snow maximum extent. When MODIS Collection 5 completed, we made comparison with both Terra and Aqua. The result is generally confirms that Aqua sees more cloud and less snow than Terra.

AVHRR data processing. To establish the longest possible time series of snow-cover area for the Tien Shan we relied on the NOAA/NASA polar-orbiting satellites optical sensors. The AVHRR LAC data used with a fractional snow cover algorithm (AVTREE) developed by Southwest Regional Earth Science Applications Center (SW-RESAC). The SAF NWC cloud cover masking algorithms was developed and validated with standard meteorological and snow cover records to compliment the AVTREE algorithm, which produced snow covered area maps from images that include cloud cover.