Changing Climate, Landcover and Water Resources in the Mountains of Central Asia over the last 60 years

Vladimir Aizen and Elena Aizen
University of Idaho
• Population grows
• Agricultural and industrial expansion/demand

1900 – 15M
2000 – 150M
The Goal

- Estimation of actual water resources of Central Asia and their changes for the last 60 years
- Climate
  - Seasonal snow cover
  - Glaciers
- Water resources of Central Asia probability forecasting
Data:
Long-term surface observational data (air temperature, precipitation, annual dates of snow appearance and disappearance), large scale topographic maps, aerial photographs, and assimilated remote sensing information. (Corona, Hexagon KH-9, Landsat, Aster, SRTM and MODIS)

Methods:
- Differences in averages \(d = \text{AVE}_{1973-03} - \text{AVE}_{1942-72}\) for two thirty-year periods 1973-2003 \(\text{AVE}_{1973-03}\) and 1942-1972 \(\text{AVE}_{1942-72}\) and T-test at 20% for precipitation and 10% for air temperature level
- Linear trends \(\alpha\) for two periods \(\alpha_{1942-72}\) and \(\alpha_{1973-03}\); coefficients of determination, F tests, at 80% for precipitation and 90% for air temperature level of significance
- Acceleration in changes for the last thirty years: \(a = \alpha_{1973-03} - \alpha_{1942-72}\); same significance as for the linear trends
- Differences in standard deviations for two periods \(d_{\text{std}} = \text{std}_{1973-03} - \text{std}_{1942-72}\) and T-test at 20% for precipitation and 10% for air temperature level.
- Geographically Weighted Regression (GWR) spatial interpolation method to interpolate spatial gaps in the meteorological data
- Georeferenced and orthorectified image processing and spectral analysis
Some latest publications on climate changes in Central Asian Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Number stations</th>
<th>Period</th>
<th>Resolution</th>
<th>Results</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tien Shan 200 &gt; 4000 m</td>
<td>110</td>
<td>1940-1991</td>
<td>Monthly</td>
<td>Air temperature +0.01C/yr Precip.+1.2 mm /yr&lt;_2000m</td>
<td>Aizen, et al., 1997</td>
</tr>
<tr>
<td>Central Asia 35-50N 75-120E</td>
<td>32</td>
<td>1951-1990</td>
<td>Summer</td>
<td>Mongolia and northern China negative trend</td>
<td>Yatagai &amp; Yasunari, 1995</td>
</tr>
<tr>
<td>Tajikistan 800-4000 m</td>
<td>4</td>
<td>1930-1991</td>
<td>Annual</td>
<td>Air temperature +2.2C and +0.4C/yr Осадки+0.05 - 0.25 mm/yr &lt;1000 m+1.82 - +5/37 &gt;2000 m</td>
<td>Finaev, 1995</td>
</tr>
<tr>
<td>Central Asia plains and foothills</td>
<td>26 +50</td>
<td>1891-1991</td>
<td>Annual and summer</td>
<td>Steady positive trend in air temperature. Decrease of total river runoff and increase in its variability for 1962-91 comparing for 1931-60</td>
<td>Konovalov, 2003; Konovalov &amp;Williams, 2005</td>
</tr>
<tr>
<td>Central Asia 68 - 3614 m 39- 45N 62-78E</td>
<td>21</td>
<td>1879-2001</td>
<td>Annual</td>
<td>Growth of air temperature + 0.027 C /yr</td>
<td>Giese et al., 2007</td>
</tr>
</tbody>
</table>
CLIMATE

251 meteor-stations used in our analysis

Differentiation by climatic regions


Number of stations by elevations:

- <500: 84
- 500-1000: 50
- 1000-1500: 38
- 1500-2000: 28
- 2000-2500: 18
- 2500-3000: 12
- 3000-3500: 11
- >3500: 7
Difference in 30-year averages of annual (A) and summer (B) air temperature
\[ \Delta T = \text{AVE1973-2003} - \text{AVE1942-1972} \]

0.65°C thirty year difference

Difference by regions, °C

Difference by altitudinal zones, °C

0.64°C thirty year difference
Acceleration of changing annual (aT_{an}) and summer (aT_{s}) air temperatures in Central Asia by regions and altitudes for the last 30 years.
Differences in 30-year averages of annual precipitation ($\Delta Pan = \text{avePan}_{1973-2003} - \text{avePan}_{1942-1972}$) over Central Asia

Surplus in annual precipitation 355 km$^3$

Average weighted altitudinal difference in annual precipitation, mm

Average weighted altitudinal difference in annual precipitation by area, km$^3$

Difference in annual precipitation by area of regions, km$^3$

Difference in annual precipitation by regions, mm

Surplus in annual precipitation 355 km$^3$
Overall decadal trends show the high dust loading for the 1960’s and 70’s, with maximum dust loading apparent for the 30’s and that is in accordance with results from 154 Chinese stations on maximum frequency of dust weather for the mid-1960’s (Qian et al; Sun et al., 2002) and the lowest in the 90’s to be one-fifth that of the 60’s.
Differences in 30-year averages of summer precipitation ($\Delta P_{s} = \text{ave}P_{s,1973-2003} - \text{ave}P_{s,1942-1972}$) over Central Asia

Altitudinal differences in average weighted summer precipitation, mm

-15 -10 -5 0 15
H, m
> 3000
2000 - 3000
1000 - 2000
-135 - 1000

Altitudinal differences in summer precipitation by area, km$^3$

-15 -10 -5 0 15
dPs, km$^3$
> 3000
2000 - 3000
1000 - 2000
-135 - 1000

Difference in average weighted summer precipitation by regions, mm

Difference in average weighted summer precipitation by area of regions, km$^3$
Difference in 30-year averages of winter precipitation
($\Delta P_w = \text{AVE1973-2003} - \text{AVE1942-1972}$)
Acceleration of changing annual precipitation for the last 60 years ($\Delta = SLOPE_{1973-2003} - SLOPE_{1942-1972}$)

Annual acceleration by regions

Annual acceleration by altitudes
SEASONAL SNOW COVER

Snow covered areas by 1,000m isohyps over the Tien Shan for the last twenty years reconstructed by surface observational, AVHRR and MODIS data.

Duration of snow melt from the date of maximum snow cover to date of it’s disappearance reduced on 30 days during the last twenty years, equal 138 days in 2007. Snow melt 30 days faster then 20 years ago. The decrease of snow cover is not linear process.
The seasonal snow covered area in Tien Shan decreased by 15% approximately 120 000 km².
## GLACIERS

Some recent publication on Central Asia glacier changes

<table>
<thead>
<tr>
<th>Authors</th>
<th>Regions</th>
<th>Period</th>
<th>Data and methods</th>
<th>Area of glacier recession, km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khromova, et al., 2003</td>
<td>Akshiirak, Inner Tien Shan</td>
<td>1977-2001</td>
<td>Map 1977, ASTER image</td>
<td>406.8-93.6 (-23%)</td>
</tr>
<tr>
<td>Vilesov and Uvarov, 2001</td>
<td>Zailiiskiy Alatau’ N. Tien Shan</td>
<td>1955-1990</td>
<td>Aerial photography</td>
<td>287.3-81.8 (-29%)</td>
</tr>
<tr>
<td>Bolch, 2006</td>
<td>Zailiiskiy Alatau’ N. Tien Shan</td>
<td>1979-1999</td>
<td>1:100000 maps, Landsat ETM</td>
<td>198.37-34.2 (-17.3%)</td>
</tr>
<tr>
<td>Niederer et al., 2008</td>
<td>Sokuluk River basin, N. Tien Shan</td>
<td>1963-1986</td>
<td>1:25,000 maps, KFA1000 satellite photo</td>
<td>31.7-4.2 (-13.3%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1986-2000</td>
<td>Landsat ETM+</td>
<td>27.5-4.7 (-17.1%)</td>
</tr>
<tr>
<td>Narama et al., 2006</td>
<td>Terskei Alatoo N. Tien Shan</td>
<td>1971-2002</td>
<td>Corona , Landsat ETM+</td>
<td>245-18 (-8%)</td>
</tr>
<tr>
<td>Liu et al., 2006</td>
<td>Aksu R. basin C. Tien Shan</td>
<td>1963-1999</td>
<td>Maps 1:100000, Landsat TM и ETM</td>
<td>176-58.6 (-3.3%)</td>
</tr>
<tr>
<td></td>
<td>Kaidu R. basin, C. Tien Shan</td>
<td>1963-2000</td>
<td></td>
<td>33-38.5 (-11.6%)</td>
</tr>
<tr>
<td>Aizen, et al. 2007</td>
<td>Akshiirak, Inner Tien Shan</td>
<td>1977-2003</td>
<td>Aerial photography, ASTER</td>
<td>406.8-35.15 (-8.6%)</td>
</tr>
</tbody>
</table>
Glacier covered area recession during the last 30 years:

- Тянь-Шань -709 км² (-7.1%)
- Алтай -86 км² (-6.2%)
Atbashi glacierized area, Inner Tien Shan, -5.6% area reduction for the last 30 years

September 2003  September 1973
Borohoro glacierized area, Eastern Tien Shan, -5.7% area reduction for the last 30 years

September 2003  September 1973
Djungarskiy Alatau glacierized area, Northern Tien Shan - 8.0% area reduction for the last 30 years

September 2003

September 1973
Aksiirak glacierized massif

<table>
<thead>
<tr>
<th>Year</th>
<th>Glacier Count</th>
<th>Glaciated Area</th>
<th>Area Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1943</td>
<td>182 glaciers</td>
<td>427 km²</td>
<td>4.2%</td>
</tr>
<tr>
<td>1977</td>
<td>194 glaciers</td>
<td>406.8 km²</td>
<td>6.5%</td>
</tr>
<tr>
<td>2003</td>
<td>178 glaciers</td>
<td>371.6 km²</td>
<td>8.7%</td>
</tr>
</tbody>
</table>

(inner Tien Shan)

Petrov Glacier

To maintain Central Asian glaciers at the current state, the increasing summer air temperature at the ELA ($T_{s\text{-ELA}}$) (equilibrium line altitude) must be offset by a corresponding increase in annual precipitation. For example, the glaciers of Tien Shan will not retreat if an increase in mean summer air temperature on 1.0 °C at ELA coincides with an increase of annual precipitation of 100 mm at ELA.

$$P_{\text{ELA}} = 0.0995T_{s\text{-ELA}} + 0.7441$$

$R^2 = 0.98$

Glaciers exist while ELA is below the upper boundary of GCA (glacier covered area) in the basin. This chain can be diagrammed as follows: climate $\rightarrow$ ELA $\rightarrow$ Glacier dimensions/configuration, and, ultimately, glacier ice volume.
Both models forecast that significant glacier degradation begins when ELA is increased by 600 m. The Central Asia GCA may shrink to about half of the current state if ELA increases another 1000 m. The number of glaciers could decrease by 40% and glacier volume by 60%.
The annual runoff of the major Tien Shan rivers is on average 67 km$^3$ yr$^{-1}$, which includes glacial melt of about 14 km$^3$ yr$^{-1}$ (20%).

For the last thirty years (1973-2003), the 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% of average.

Relative changes of the last thirty year annual mean ($dQ_{an}/Q_{an}$) and maximum ($dQ_{max}/Q_{max}$) river runoff in comparison to sixty year averages, %, and changes in dates of maximum river runoff ($ddQ_{max}$).
Differences in 30-year averages of annual (dQan) and glacier (Qgl) river runoff (a) and their relation (b).
Significant temporal and spatial changes have occurred in Central Asia in the inter-annual surface water distribution between upper, middle, and lower river reaches, while annual runoff did not changed significantly.

Precipitation and potential evaporation have similar ranges.
The Magicc&ScenGen Global Climatic Model (IPCC, 2001) scenarios considered that annual average air temperature in Central Asia by 2100 increases between 1.8 and 4.4°C and precipitation by 6% of current rate.

Ratios between predicted by 2100 and current river runoff (R/Rc), evapotranspiration (E/Ec), potential evaporation (E*/Ec') under predicted changes of air temperature (T_c+d; d=1,2,…5°C) and precipitation (mPc, m=0.9; 1, 1.1, …1.5) for the Sir Dar’ya R. basin.
Conclusion

Rapid current decline of water resources in central Asia related to factors such as:

- (i) the rise of global and regional air temperatures
- (ii) shrinkage of seasonal snow cover and degradation of glaciers
- (iii) decrease of precipitation in the Alpine areas
- (iv) partitioning among snow and rain, evaporation fluxes
- (v) poor management of regional water resources.

The diminishing natural water storages significantly affect river runoff, lake levels, and groundwater in aquifers, and contribute to progressive droughts that cause salinization and desertification in central Asia.