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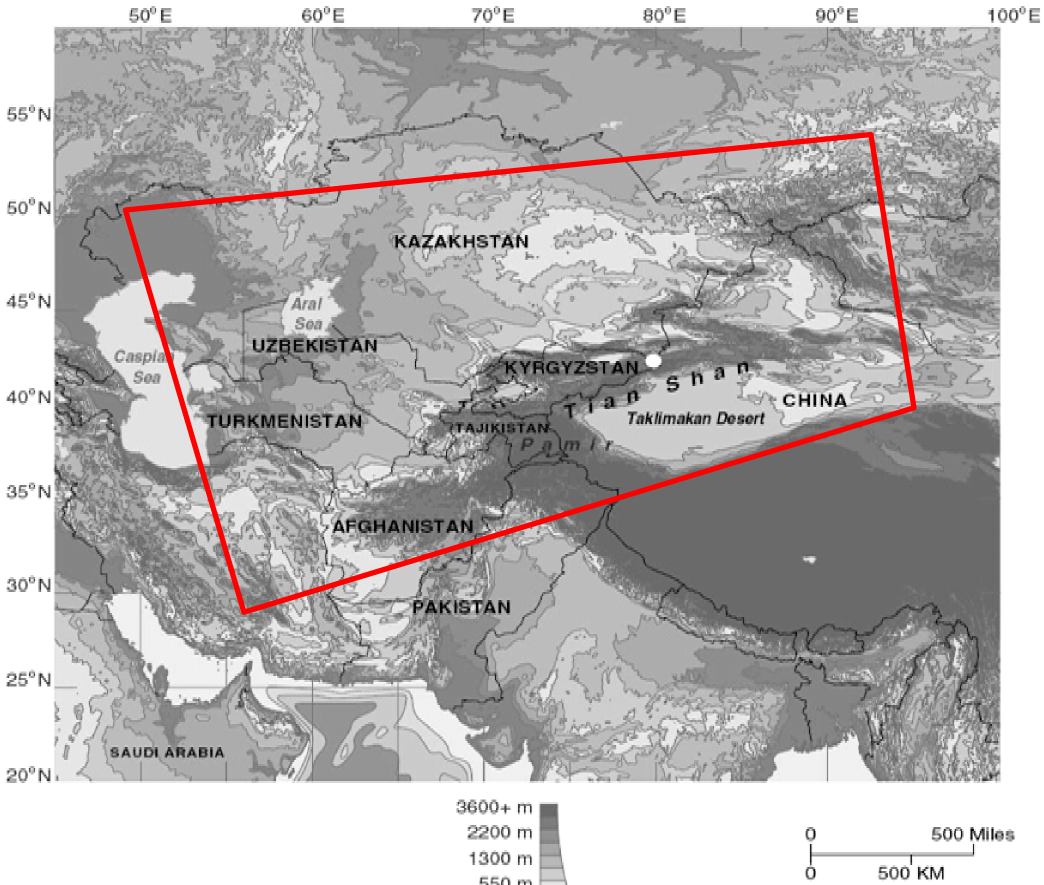
Changing Climate, Landcover and Water Resources in the Mountains of Central Asia over the last 60 years

- Population grows
- Agricultural and industrial expansion/demand

2000 – 150M

1900 – 15M







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 ($d = AVE_{1973-03} - AVE_{1942-72}$) for two thirty-year periods 1973-2003 ($AVE_{1973-03}$) and 1942-1972 ($AVE_{1942-72}$) and T-test at 20% for precipitation and 10% for air temperature level
- Linear trends (α) 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 ($d_{std} = std_{1973-03} - std_{1942-72}$) 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

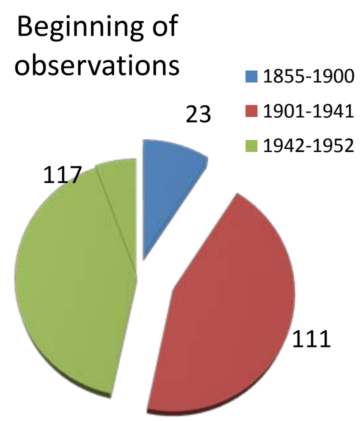
Some latest publications on climate changes in Central Asian

Region	Number stations	Period	Resolution	Results	Authors
Tien Shan 200 > 4000 m	110	1940-1991	Monthly	Air temperature +0.01C/yr Precip.+1.2 mm /yr<2000m	Aizen, et al., 1997
Central Asia 35-50N 75-120E	32	1951-1990	Summer	Mongolia and northern China negative trend	Yatagai & Yasunari, 1995
Tajikistan 800-4000 m	4	1930-1991	Annual	Air temperature +2.2C and +0.4C/yr Осадки+0.05 - 0.25 mm/yr <1000 m+1.82 - +5/37 >2000 m	Finaev, 1995
Central Asia plains and foothills	26 +50	1891-1991	Annual and summer	Steady positive trend in air temperature. Decrease of total river runoff and increase in its variability for 1962-91 comparing for 1931-60	Konovalov, 2003; Konovalov &Williams, 2005
Central Asia 68 - 3614 m 39- 45N 62-78E	21	1879-2001	Annual	Growth of air temperature + 0.027 C /yr	Giese et al., 2007
Xinjiang	9	1979–1999	Summer	Successive droughts for 3 summers (1997-99) at northern China	Xu, 2001

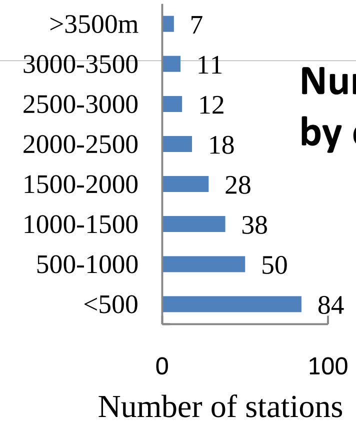
CLIMATE

251 meteor-stations used in our analysis

Differentiation by climatic regions



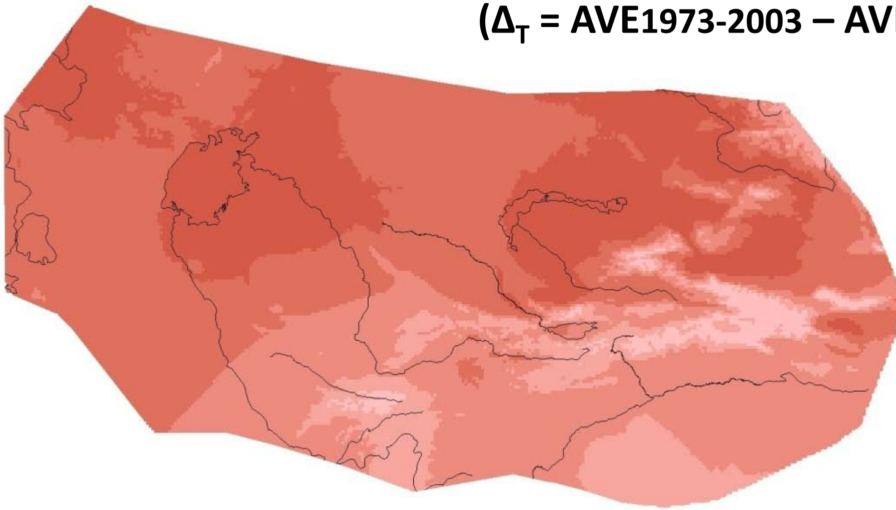
Major period of observations: 1942-1972 and 1973-2003



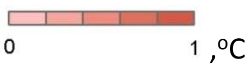
Number of stations by elevations

Difference in 30-year averages of annual (A) and summer (B) air temperature
(Δ_T = AVE1973-2003 – AVE1942-1972)

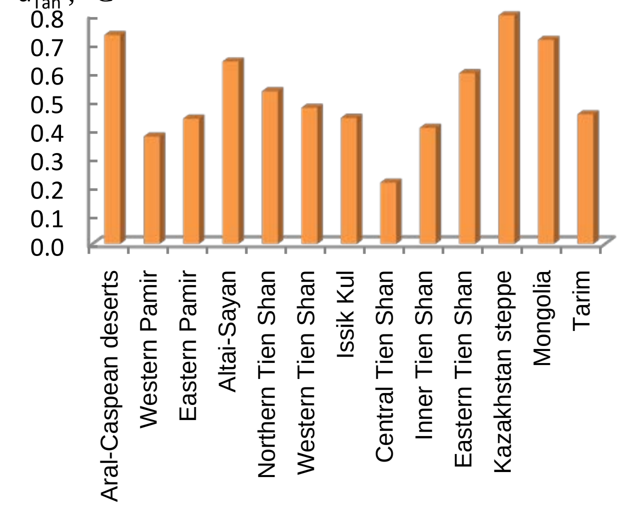
A



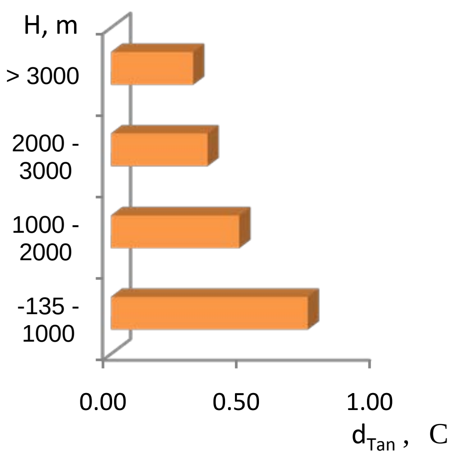
0.65°C thirty year difference



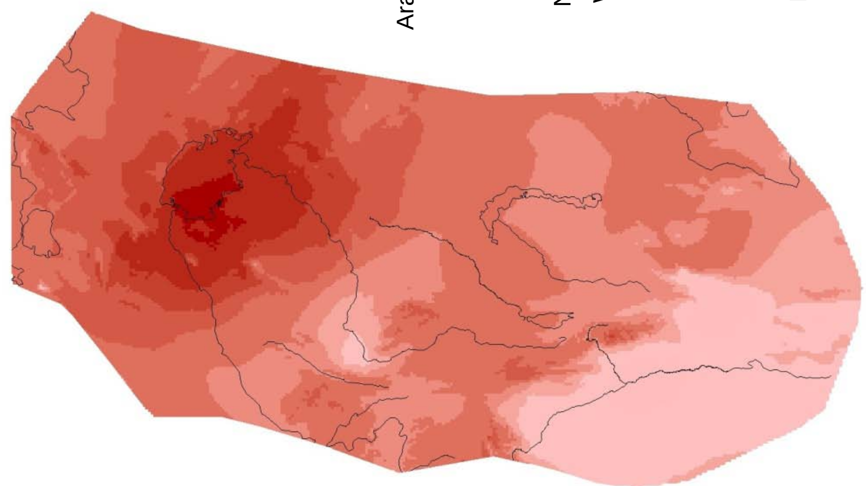
Difference by regions, °C



Difference by altitudinal zones, °C



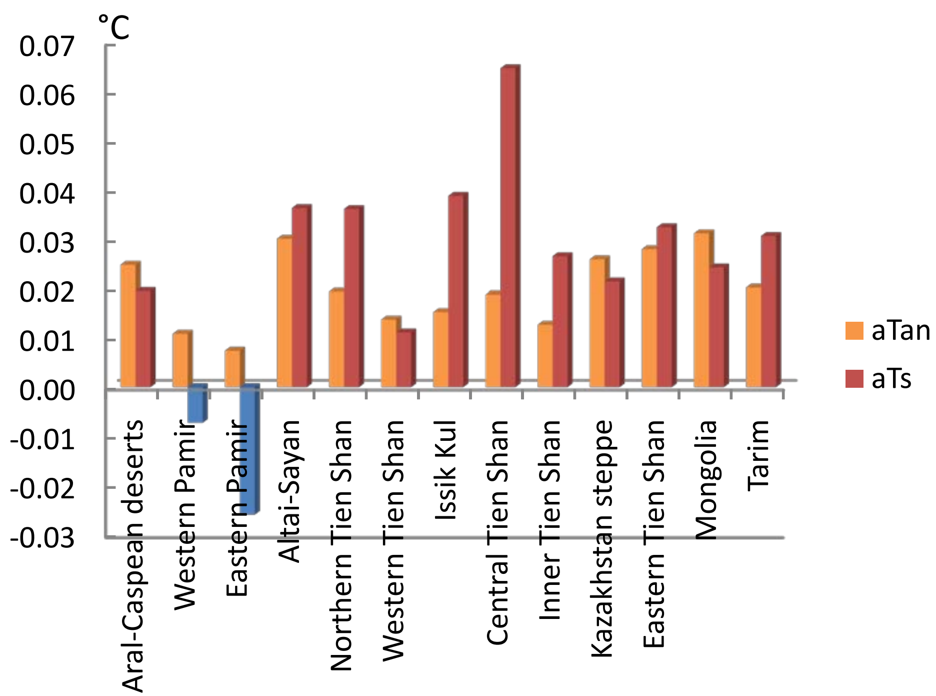
B



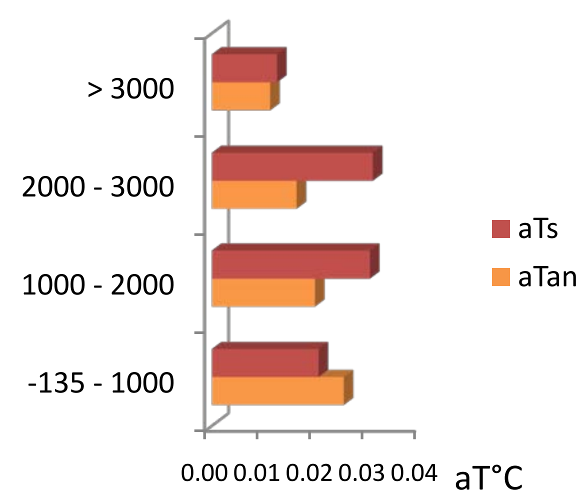
0.64°C thirty year difference

Acceleration of changing annual (aT_{an}) and summer (aT_s) air temperatures in Central Asia by regions and altitudes for the last 30 years

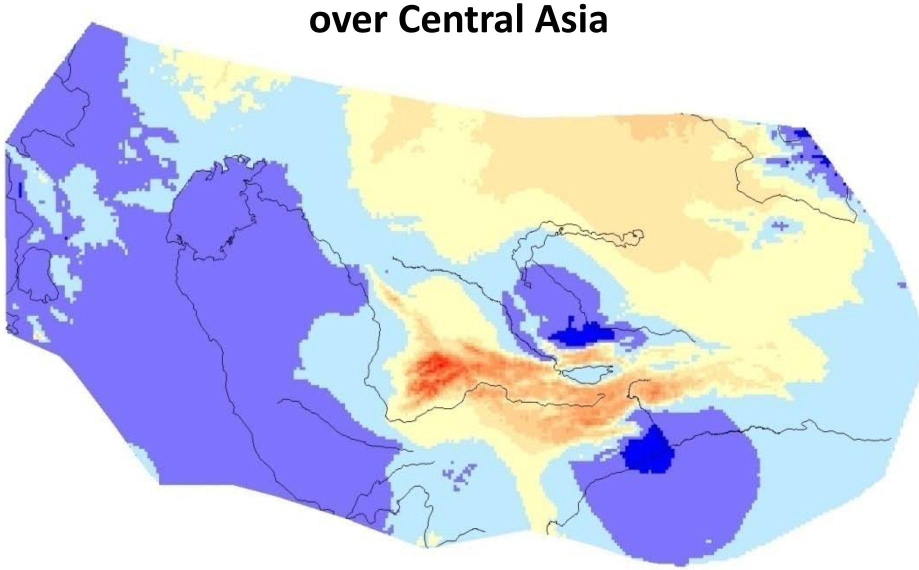
Acceleration by regions, °C



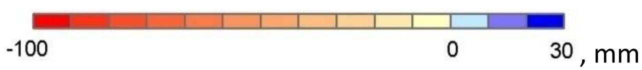
Acceleration by altitudinal zones, °C

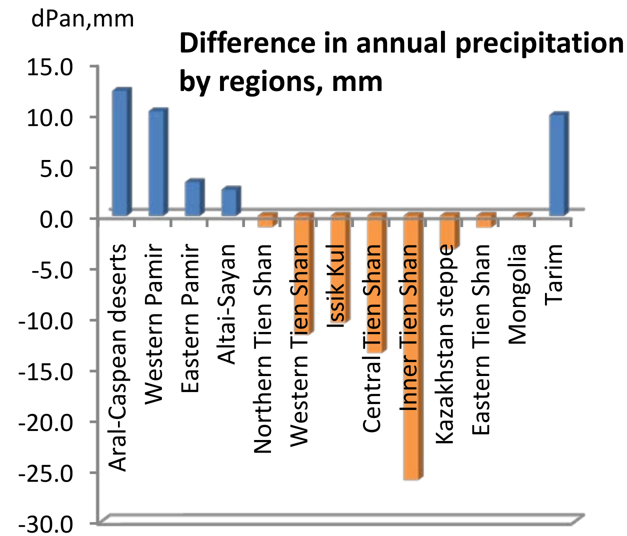


Differences in 30-year averages of annual precipitation ($\Delta Pan = avePan_{1973-2003} - avePan_{1942-1972}$) over Central Asia

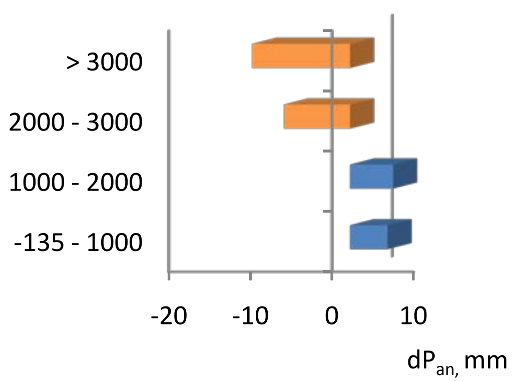


Surplus in annual precipitation 355 km^3

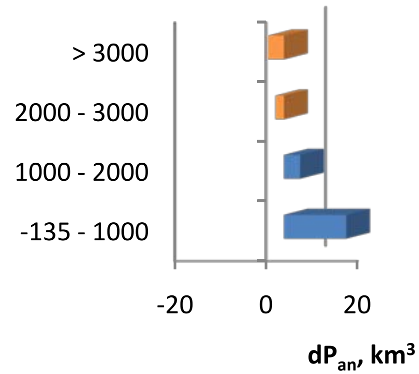


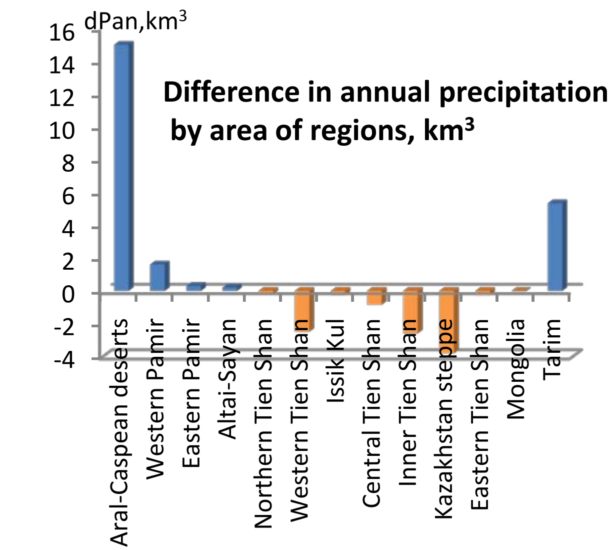


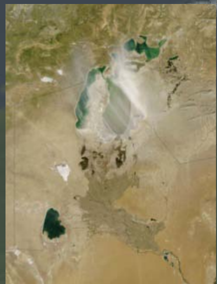
Average weighted altitudinal difference in annual precipitation, mm

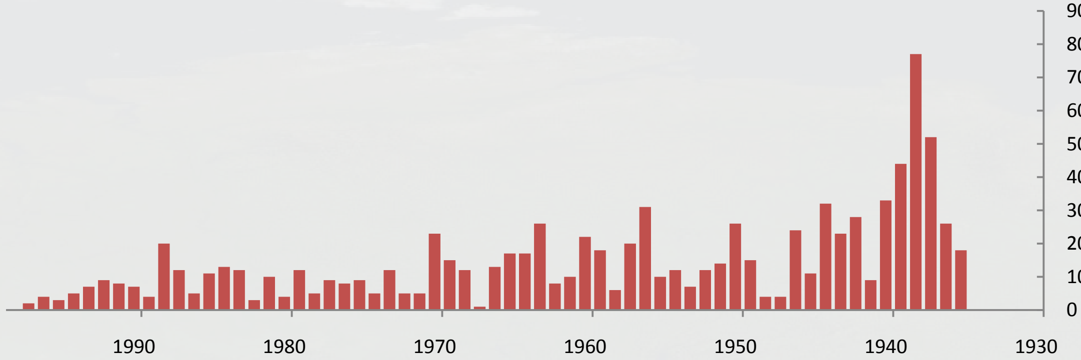


Average weighted altitudinal difference in annual precipitation by area, km^3

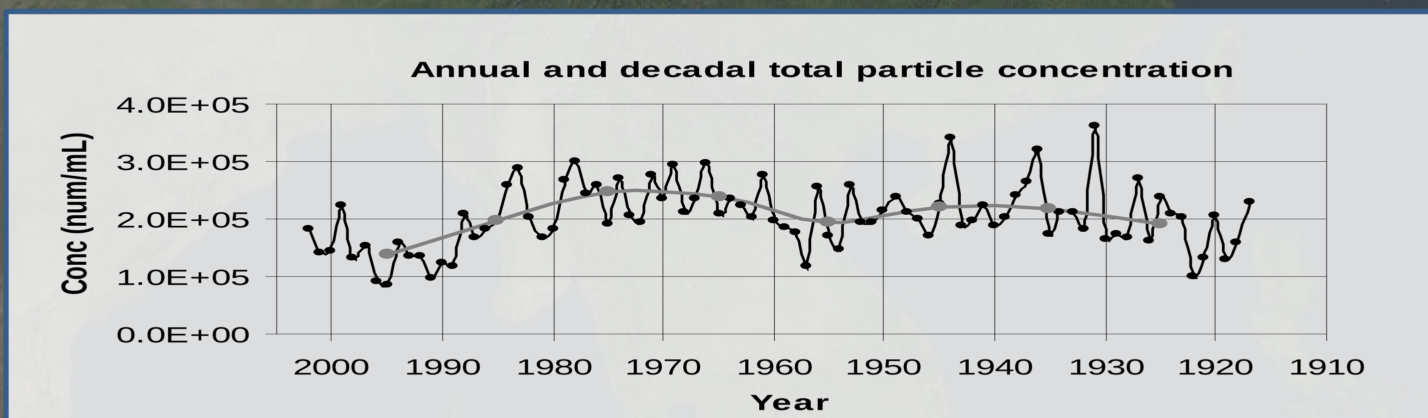




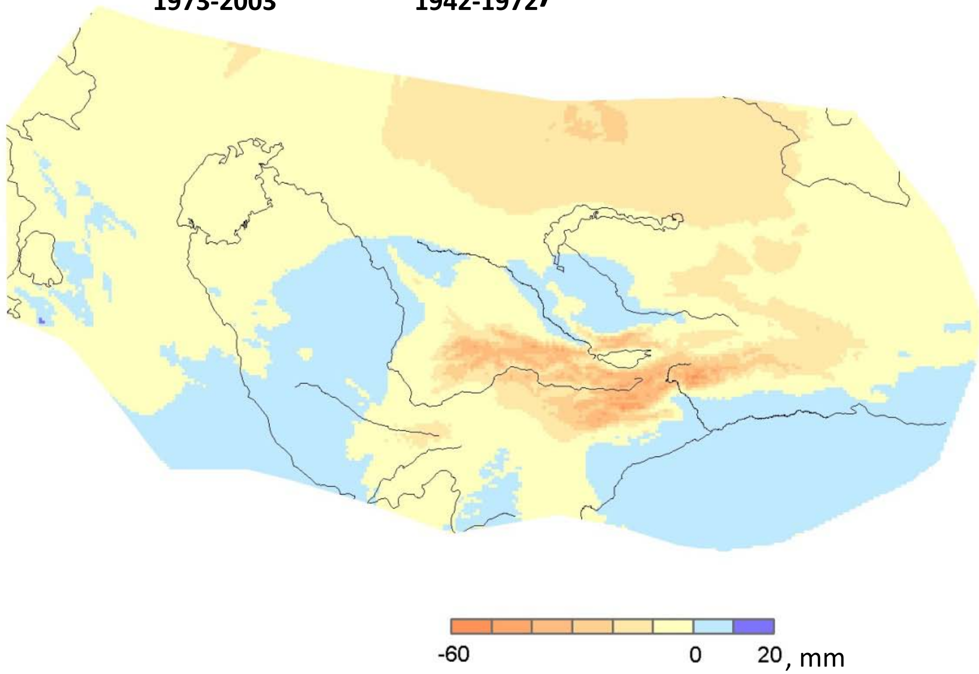




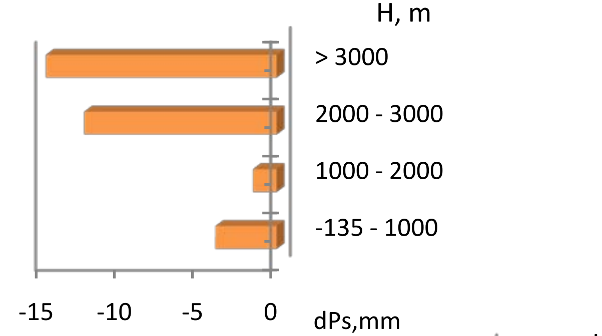
Overall decadal trends show the high dust loading for the 1960's and 70's, with maximum dust loading apparent for the 30's and that is in accordance with results from 154 Chinese stations on maximum frequency of dust weather for the mid-1960's (*Qian et al; Sun et al., 2002)* and the lowest in the 90's to be one-fifth that of the 60's.



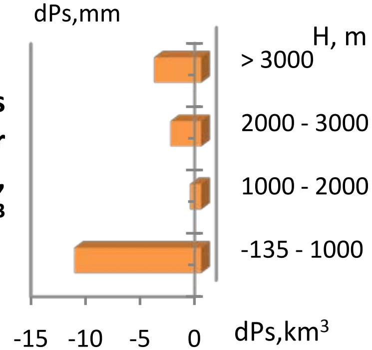
Differences in 30-year averages of summer precipitation ($\Delta Ps = avePs_{1973-2003} - avePs_{1942-1972}$) over Central Asia



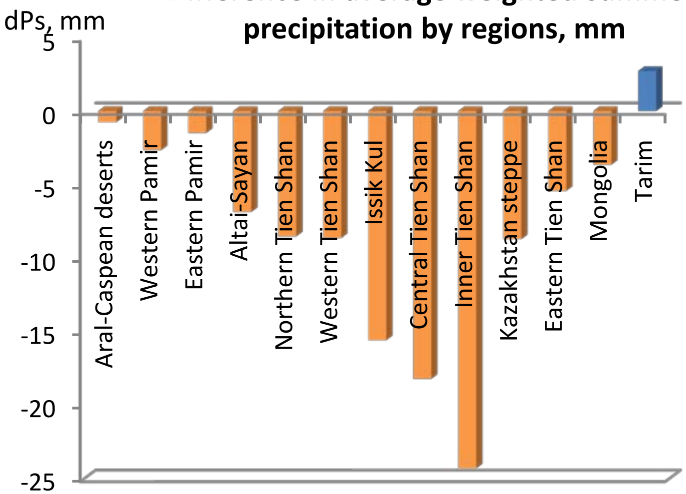
Altitudinal differences in average weighted summer precipitation, mm



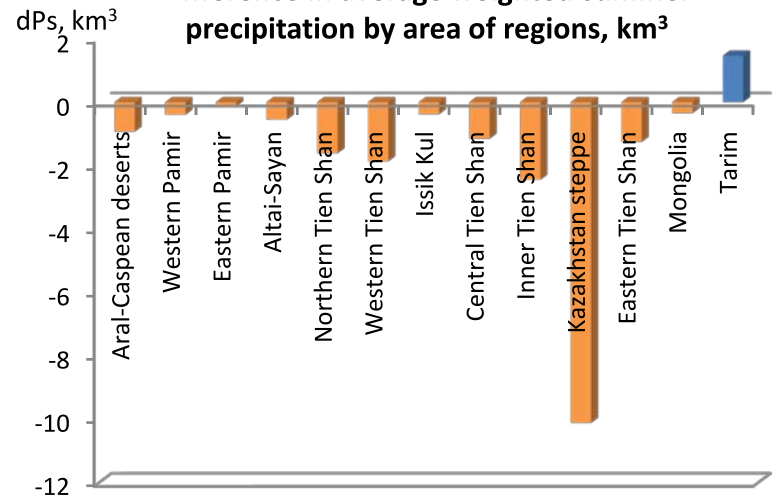
Altitudinal differences in summer precipitation by area, km^3



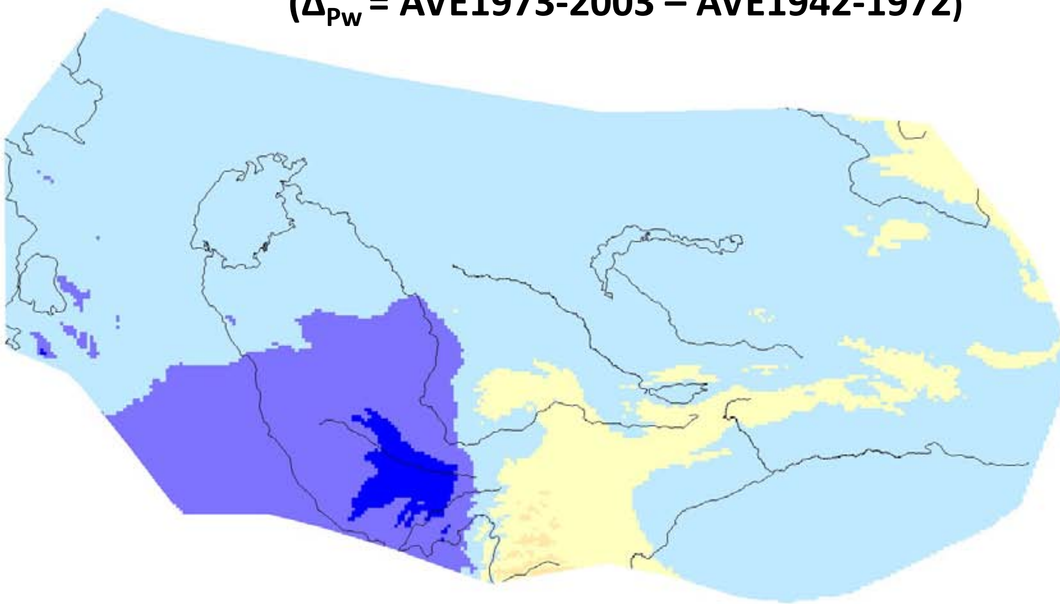
Difference in average weighted summer precipitation by regions, mm

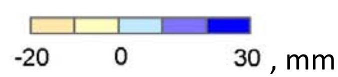


Difference in average weighted summer precipitation by area of regions, km^3

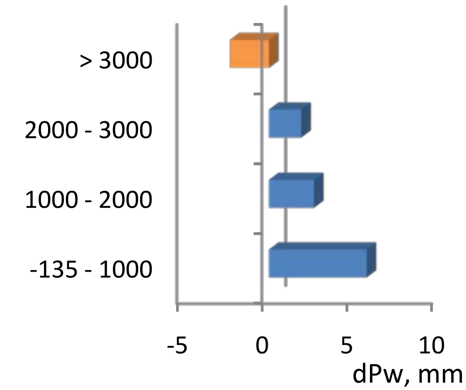


Difference in 30 -year averages of winter precipitation (Δ_{Pw} = AVE1973-2003 – AVE1942-1972)

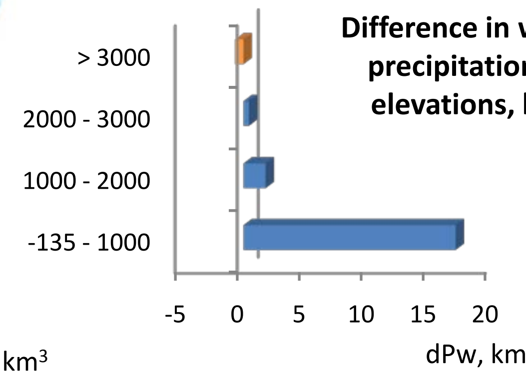




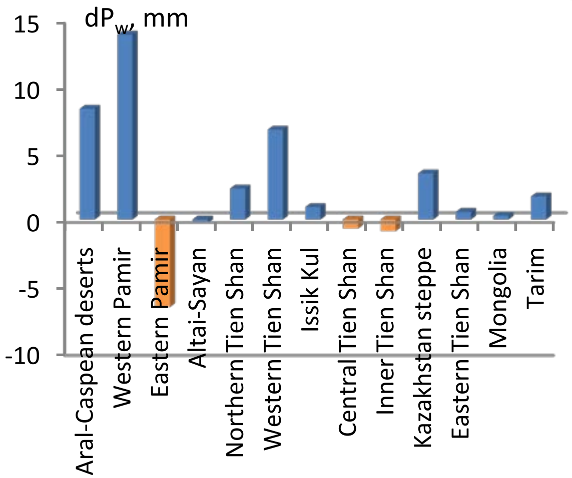
Difference in average weighted winter precipitation by elevation, mm



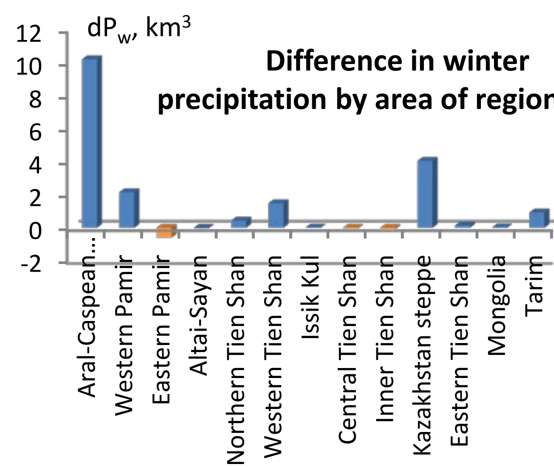
Difference in winter precipitation by elevations, km³



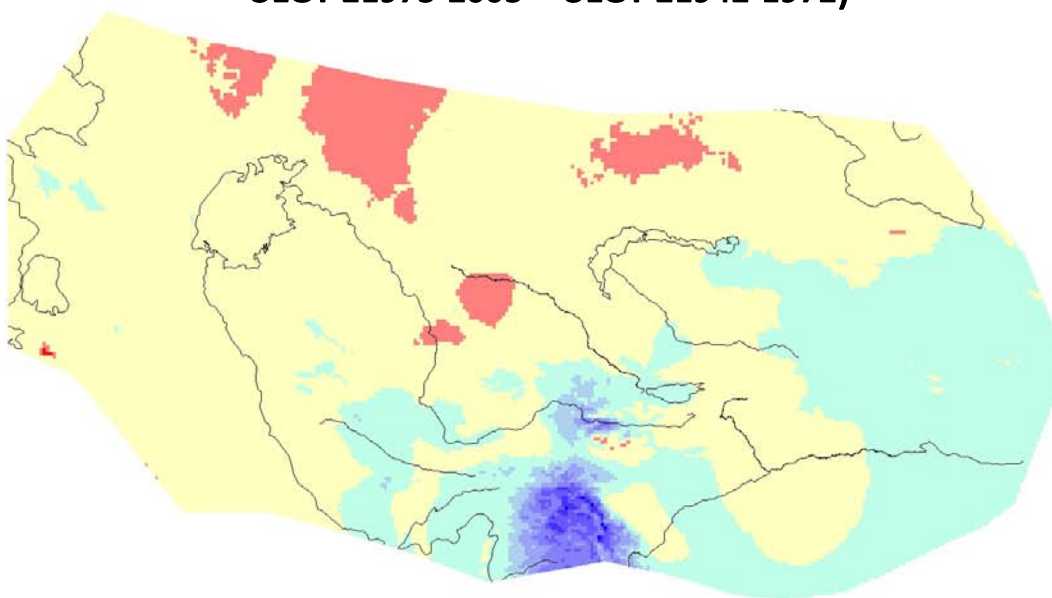
Difference in average weighted winter precipitation by regions, mm



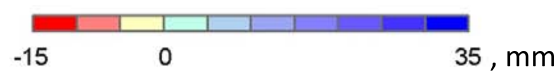
Difference in winter precipitation by area of regions , км³

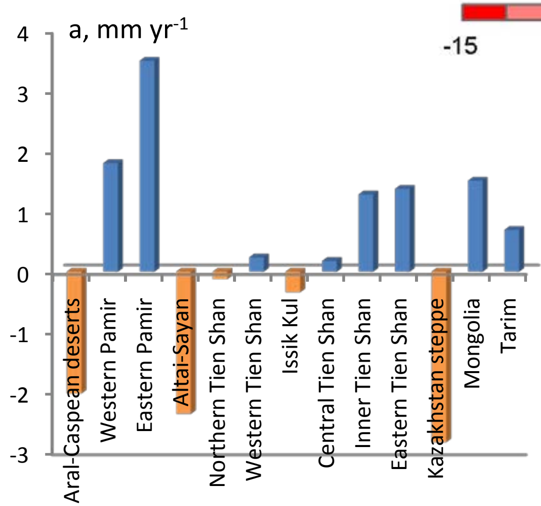


Acceleration of changing annual precipitation for the last 60 years (Δ = SLOPE1973-2003 – SLOPE1942-1972)

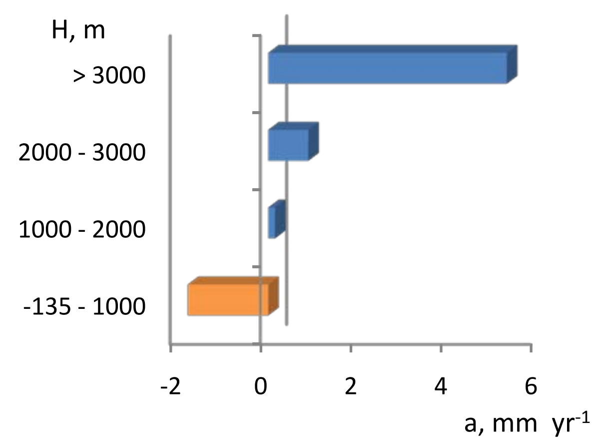


Annual acceleration by regions





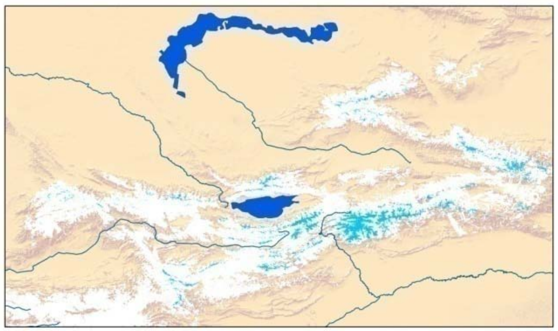
Annual acceleration by altitudes



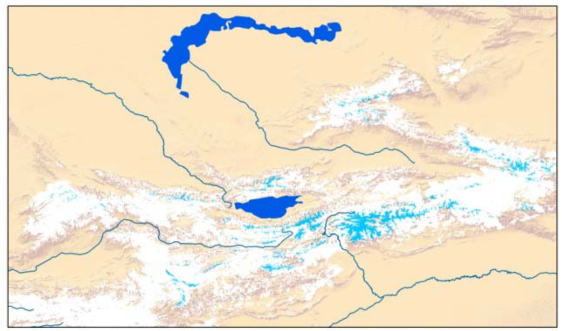
SEASONAL SNOW COVER

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

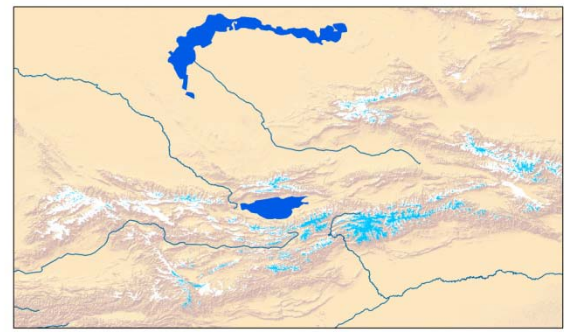
Duration of snow melt from the date of maximum snow cover to date of it’s disappearance reduced on 30 days during the last twenty years, equal 138 days in 2007. Snow melt 30 days faster then 20 years ago. The decrease of snow cover is not linear process.



AVHRR 30 April 1987

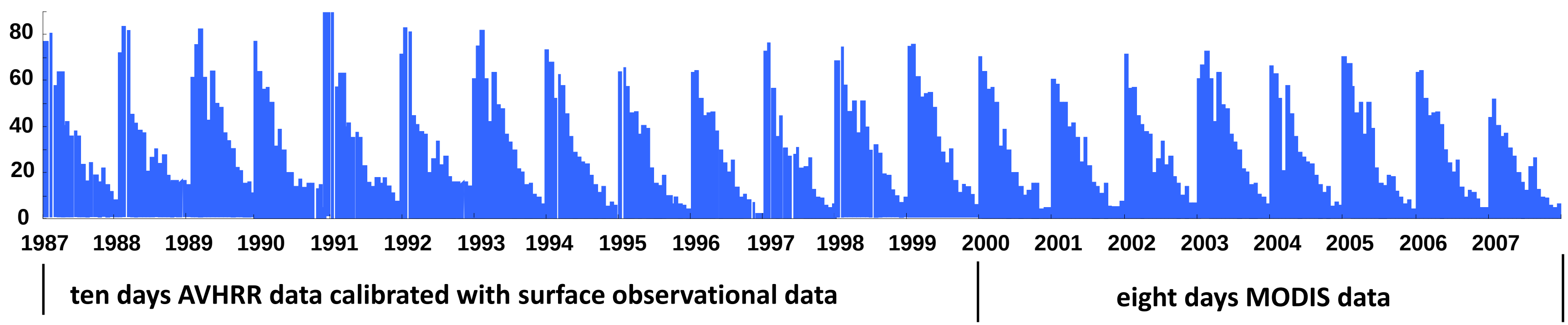


AVHRR 15 April 1996

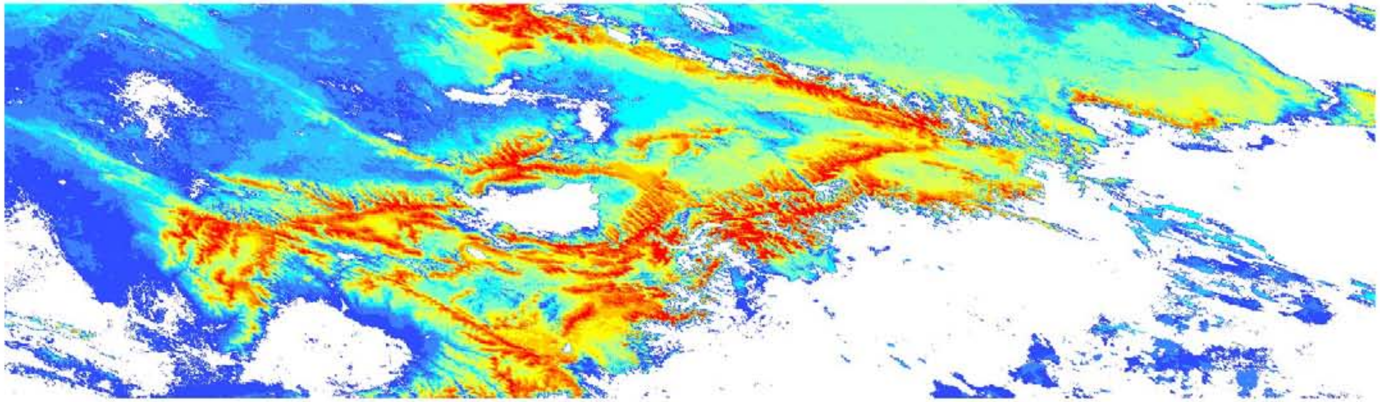


MODIS 15 April 2007

snow cover, %

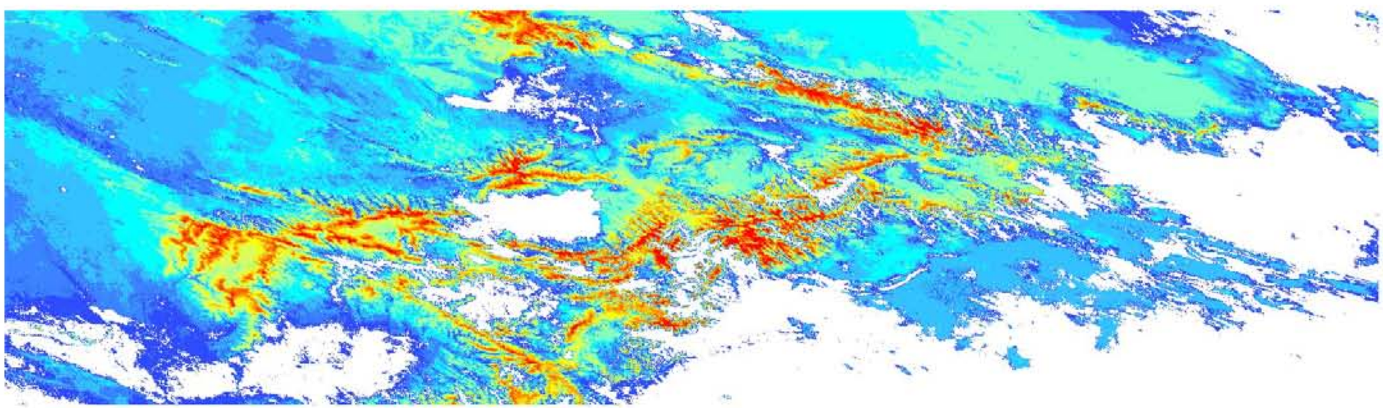


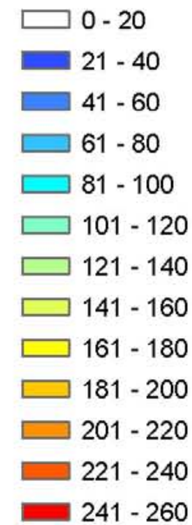
Tien Shan, number of days with snow 2000-2001



The seasonal snow covered area in Tien Shan decreased by 15% approximately 120 000 km^2

Tien Shan, number of days with snow 2006-2007





GLACIERS

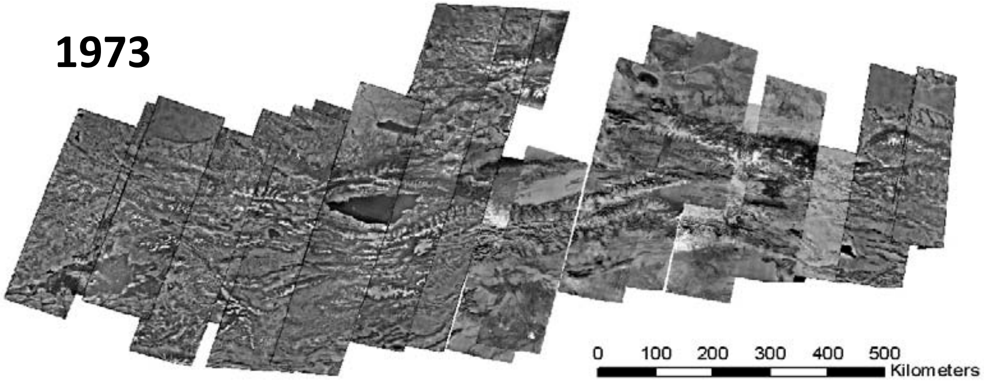
Some recent publication on Central Asia glacier changes

Authors	Regions	Period	Data and methods	Area of glacier recession, km^2
Khromova , et al., 2003	Akshiirak, Inner Tien Shan	1977-2001	Map 1977, ASTER image	406.8 -93.6 (-**23**%)
Vilesov and Uvarov, 2001	Zailiiskiy Alatau' N. Tien Shan	1955-1990	Aerial photography	287.3 -81.8 (-**29**%)
Bolch, 2006	Zailiiskiy Alatau N. Tien Shan	1979-1999	1:100000 maps, Landsat ETM	198.37 -34.2 (-**17.3**%)
Niederer *et al.* 2008	Sokuluk River basin, N. Tien Shan	1963-1986	1:25,000 maps, KFA1000 satellite photo	31.7 -4.2 (-**13.3**%)
		1986-2000	Landsat ETM+	27.5 -4.7 (-**17.1**%)
Ye *et al.* 2005	Glacier № 1 Urumqi R. basin E. Tien Shan	1962-2003	Maps 1962, 1964, 1986, 1992, 1994, 2000 and 2001	1.94 -0.24 (-**12.4**%)
Narama *et al.,* 2006	Terskei Alatoo N. Tien Shan	1971-2002	Corona , Landsat ETM+	245 -18 (-**8**%)
Liu *et al.,* 2006	Aksu R. basin C. Tien Shan	1963-1999	Maps 1:100000, Landsat TM и ETM	176 -58.6 (-**3.3**%)
	Kaidu R. basin, C. Tien Shan	1963-2000		33 -38.5 (-**11.6**%)
Aizen*, et al.* 2007	Akshiirak, Inner Tien Shan	1977-2003	Aerial photography, ASTER	406.8 35.15 (-**8.6**%)

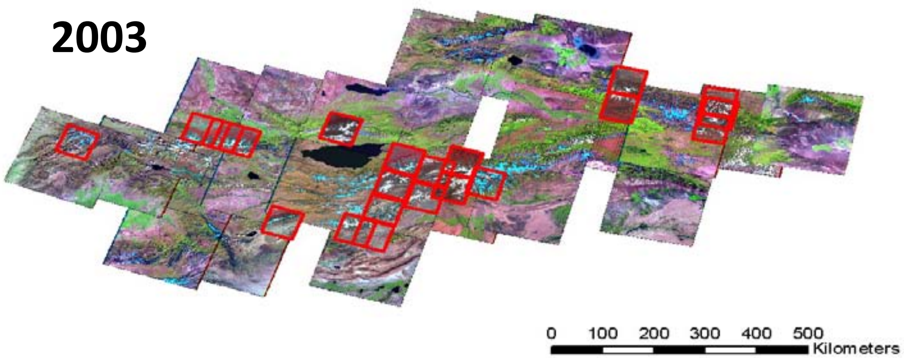
Glacier covered area recession during the last 30 years:

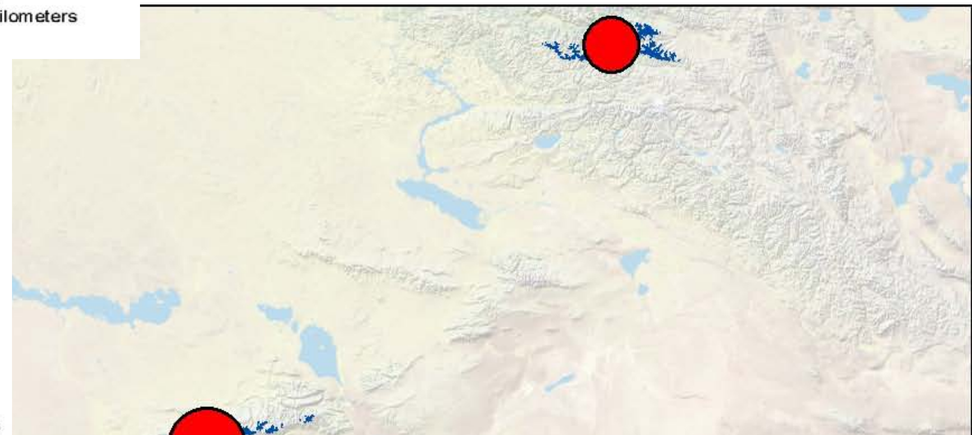
- Тянь-Шань -709 км^2 (-7.1%)
- Алтай -86 км^2 (-6.2%)

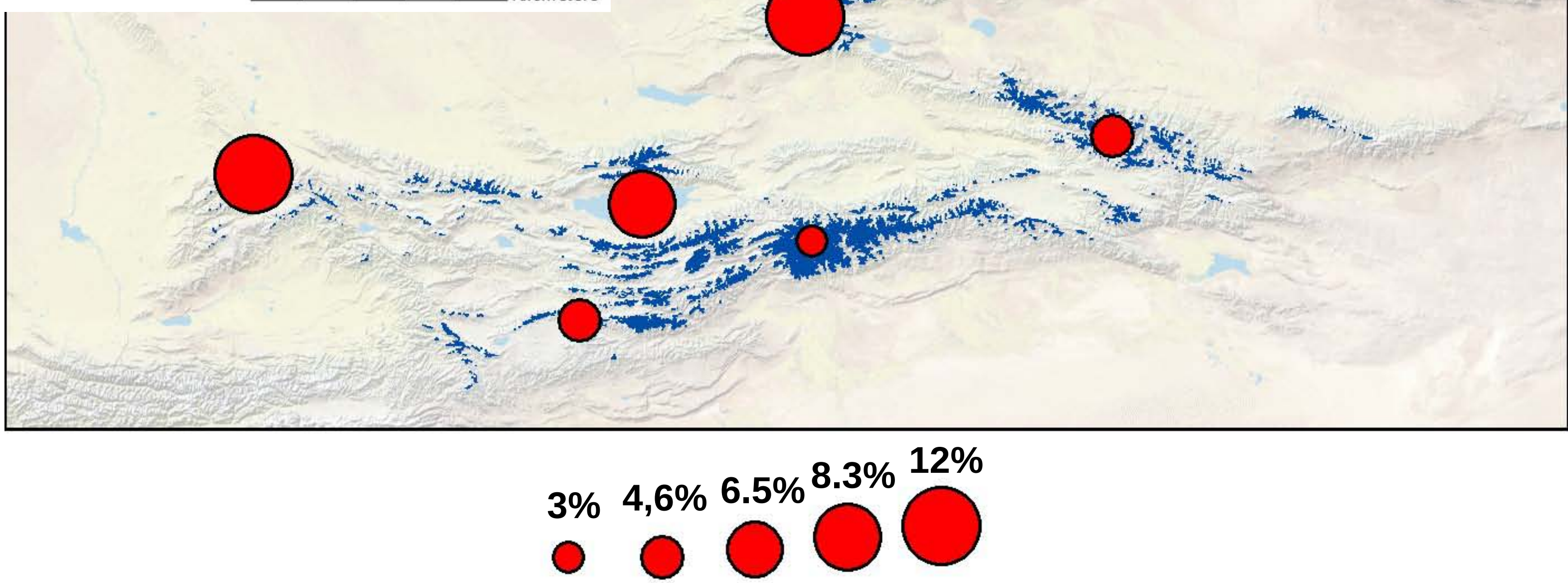
1973



2003

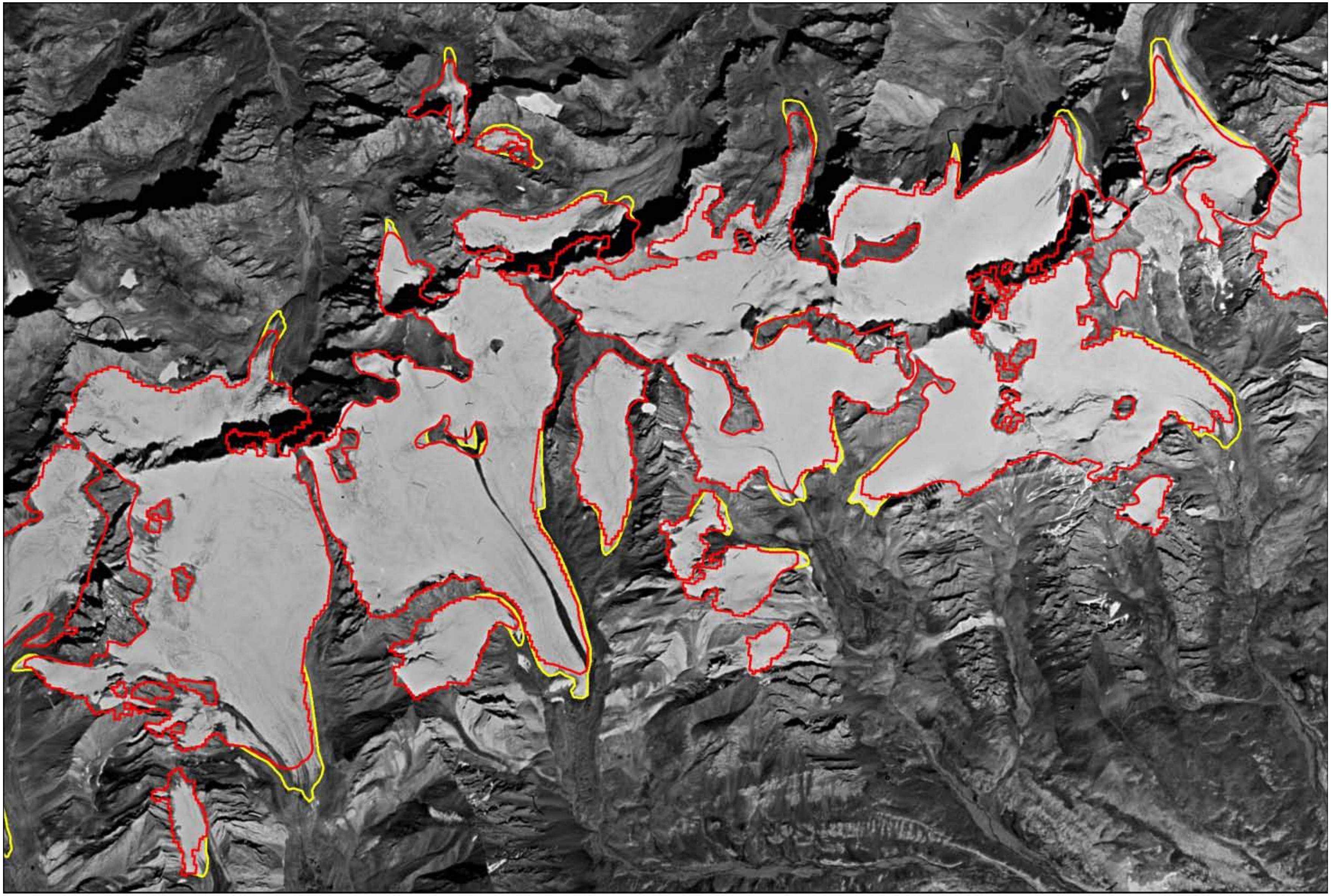






Atbashi glacierized area, Inner Tien Shan, -5.6% area reduction for the last 30 years

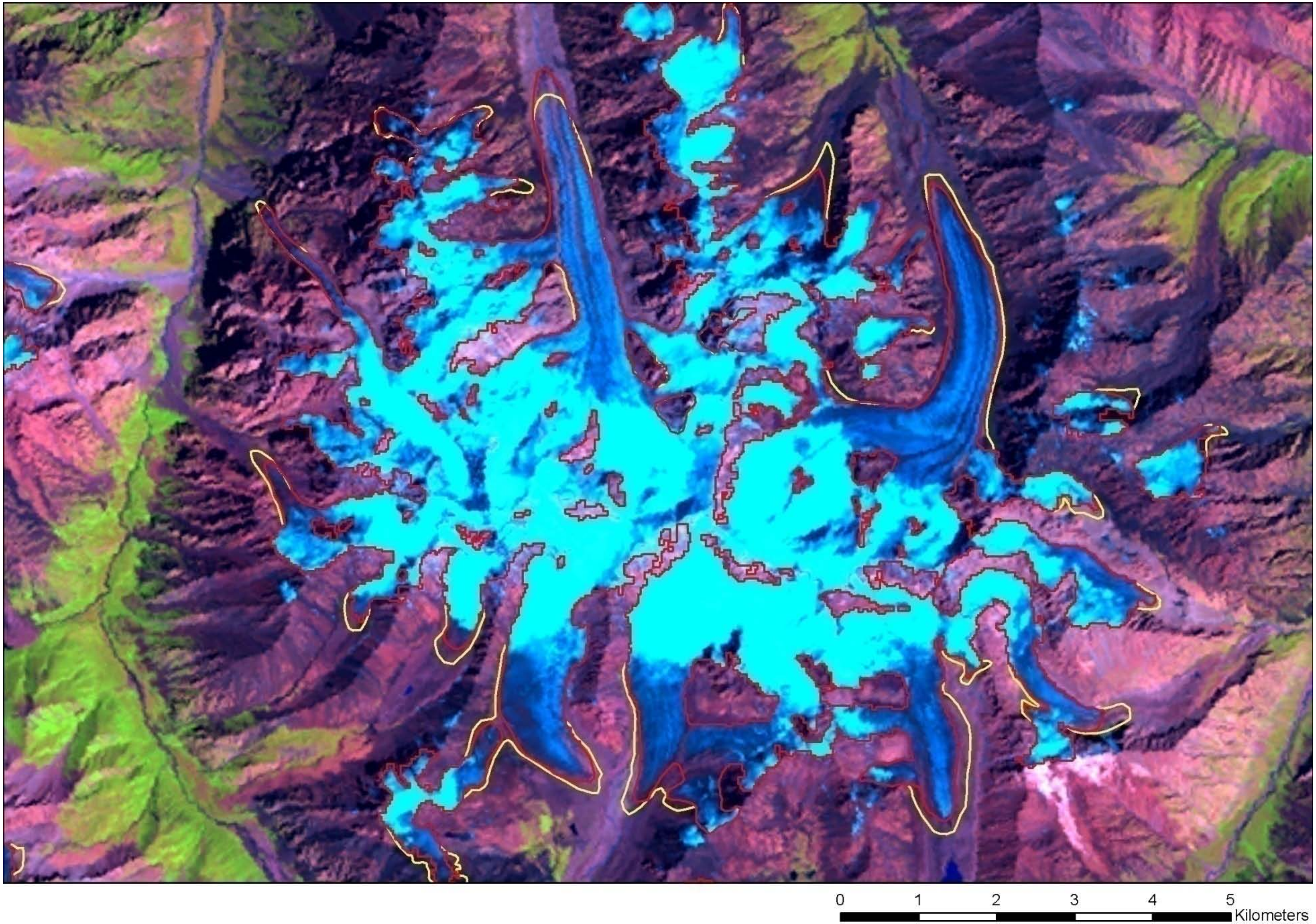
September 2003 September 1973



0 1 2 3 Kilometers

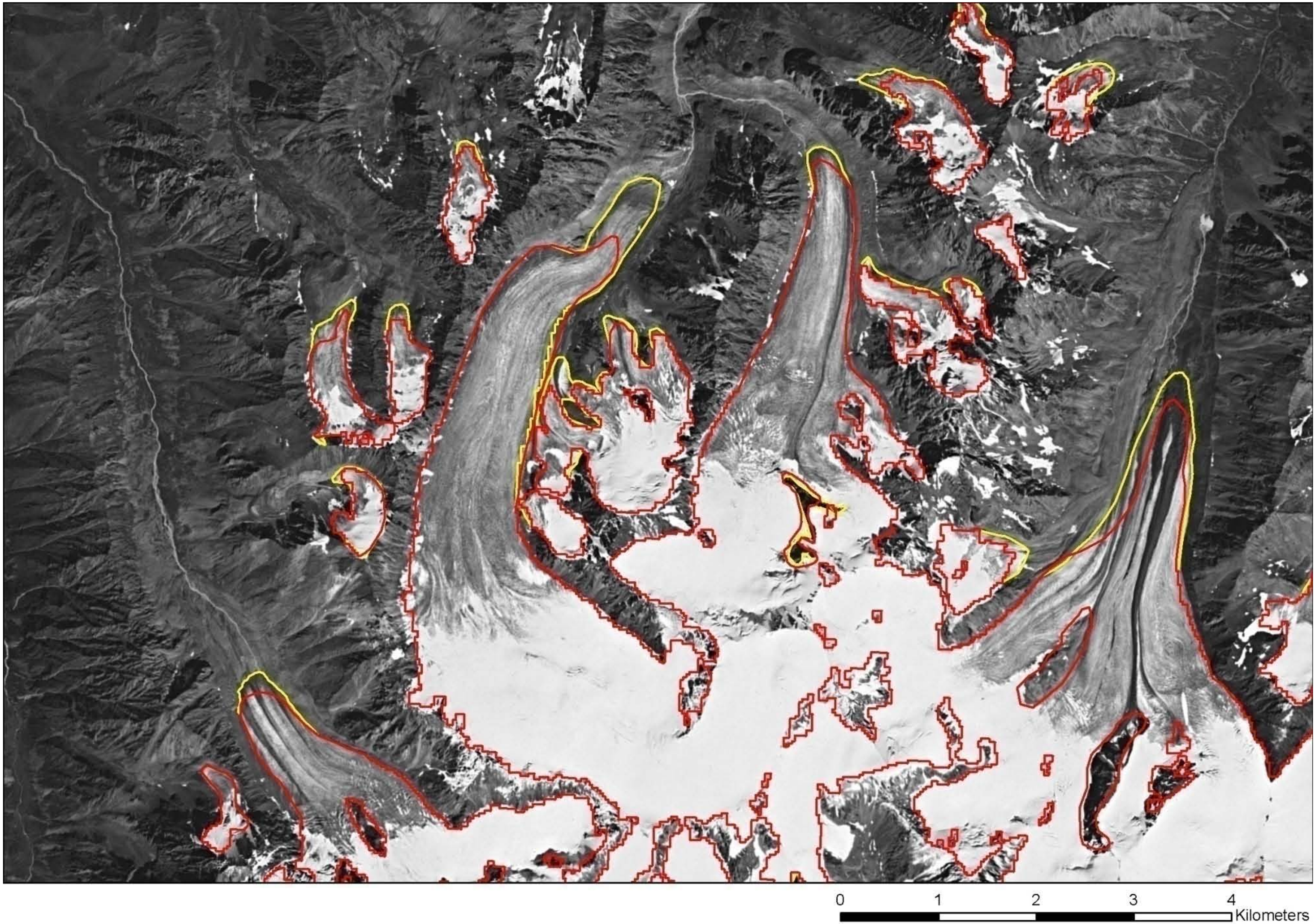
Borohoro glacierized area, Eastern Tien Shan, -5.7% area reduction for the last 30 years

September 2003 September 1973



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

September 2003 September 1973



Inner Tien Shan

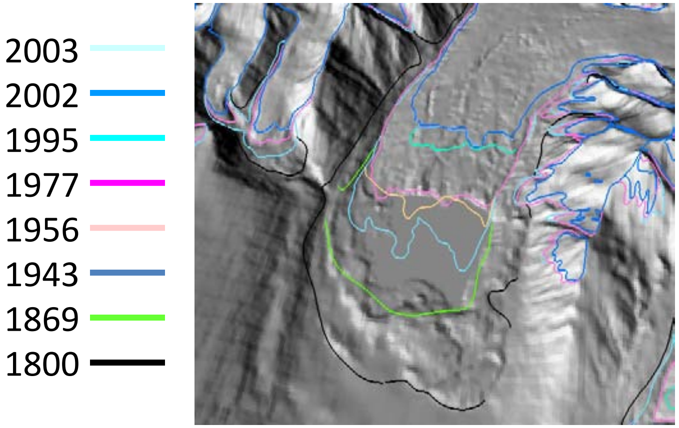
Axial glacierized massif

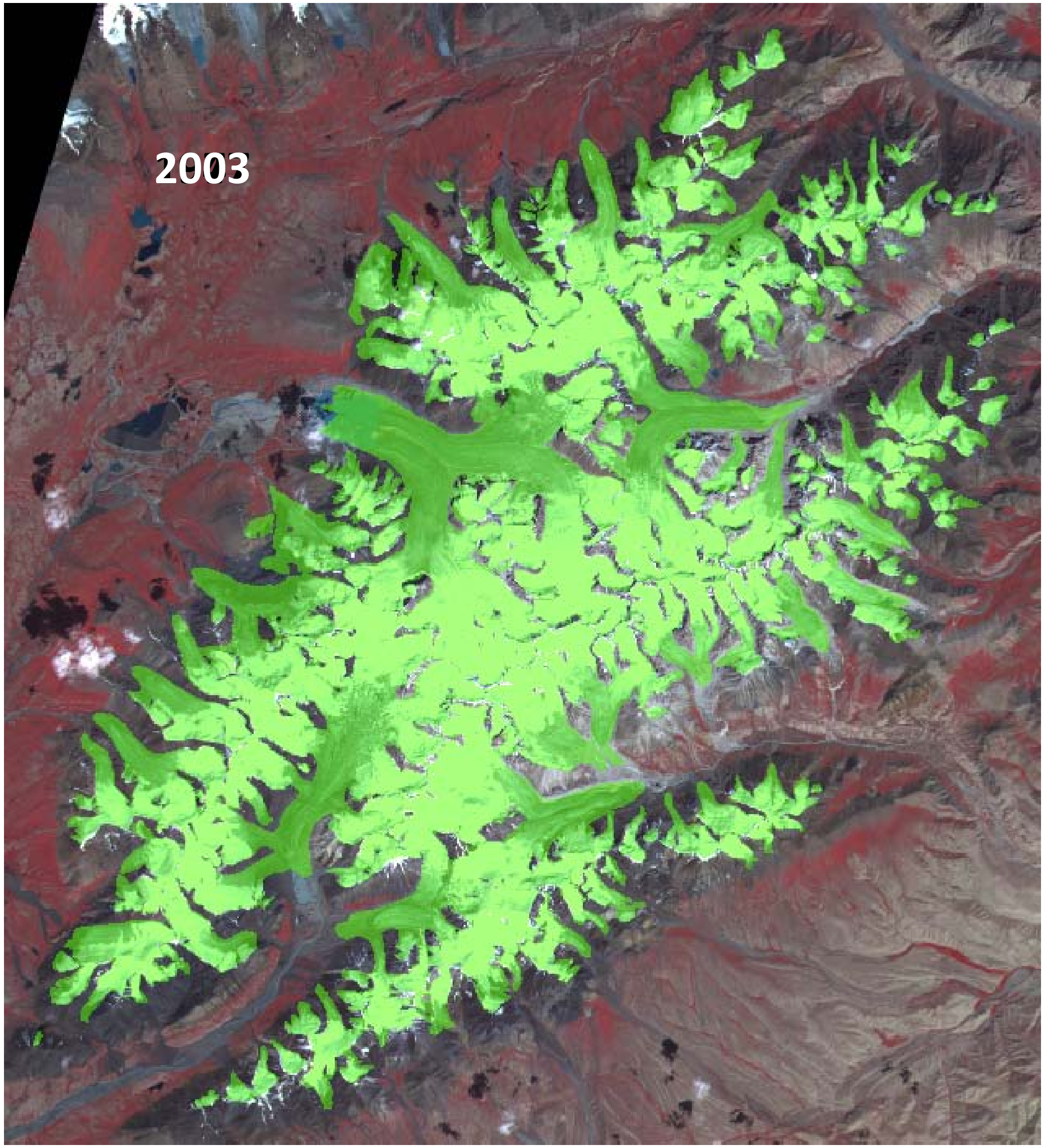
glacierized area

area

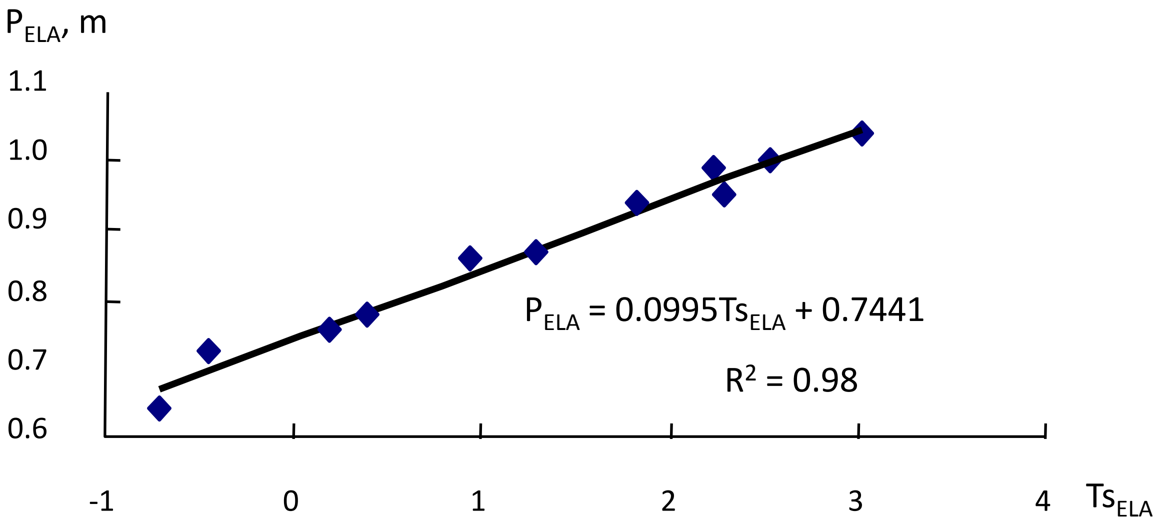
(aerial photogrammetry 1977/ASTER 2003)

Petrov Glacier



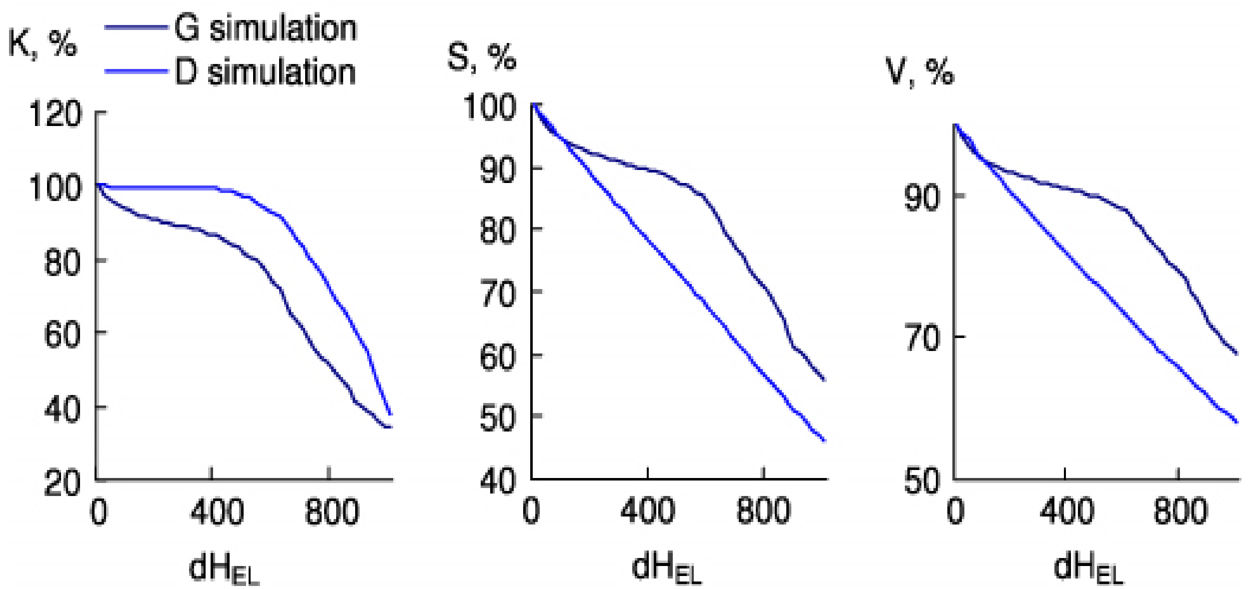


To maintain Central Asian glaciers at the current state, the increasing summer air temperature at the $\overline{ELA}$ ($T_{s\ \overline{ELA}}$) (equilibrium line altitude) must be offset by a corresponding increase in annual precipitation. For example, the glaciers of Tien Shan will not retreat if an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



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 → ELA → Glacier dimensions/configuration, and, ultimately, glacier ice volume.

Forecasted decrease in number of glaciers (K), glacier covered areas (S) and volume (V) relatively to current glacier covered area under the ELA moving up

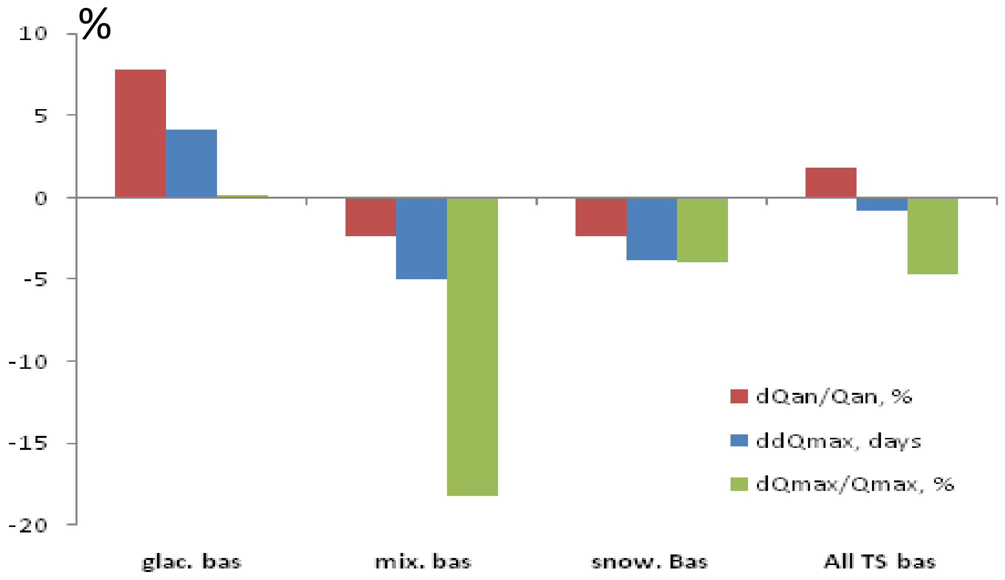


Both models forecast that significant glacier degradation begins when ELA is increased by 600 m . The Central Asia GCA may shrink to about half of the current state if ELA increases another 1000 m. The number of glaciers could decrease by 40% and glacier volume by 60%.

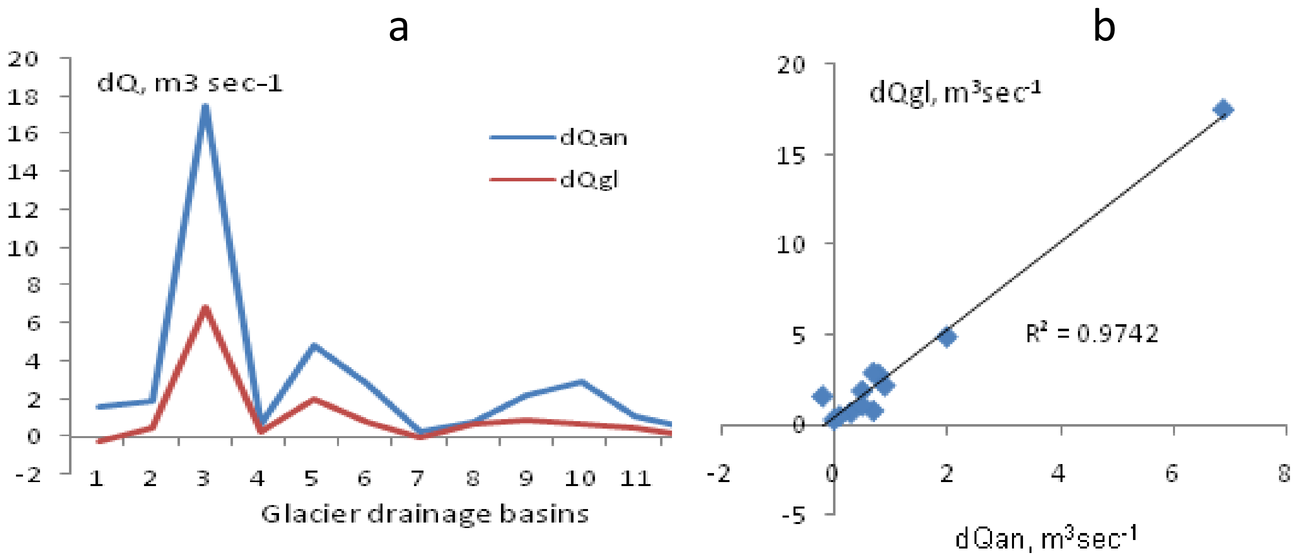
RIVER RUNOFF

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

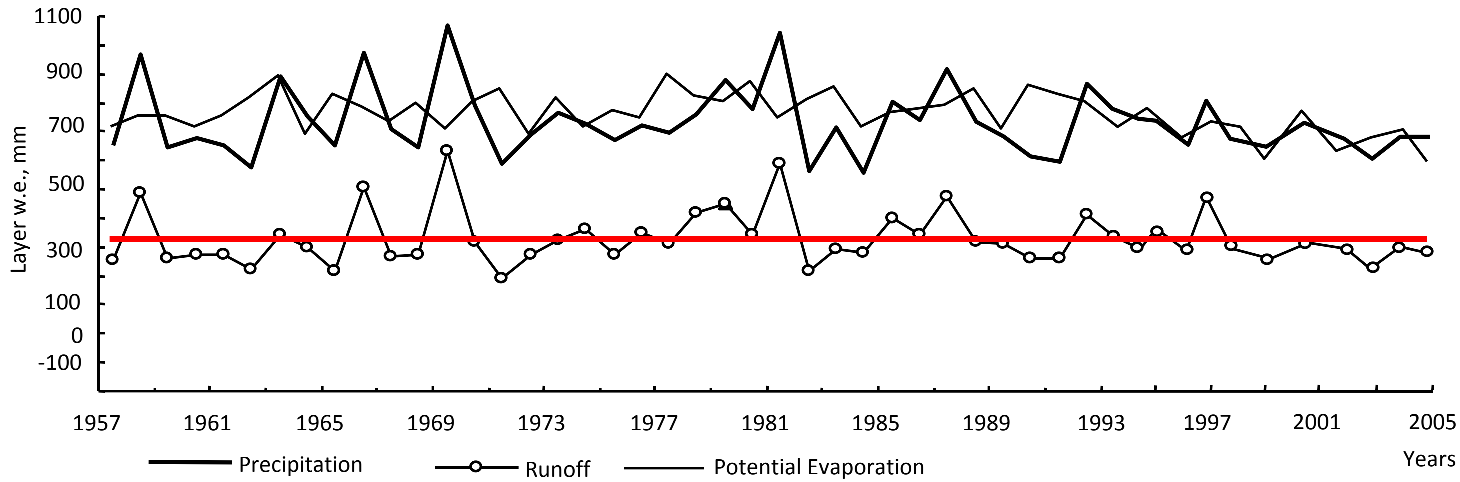


Relative changes of the last thirty year annual mean (dQan/Qan) and maximum (dQmax/Qmax) river runoff in comparison to sixty year averages, % , and changes in dates of maximum river runoff (ddQmax).



Differences in 30-year averages of annual (dQan) and glacier (Qgl) river runoff (a) and their relation (b).

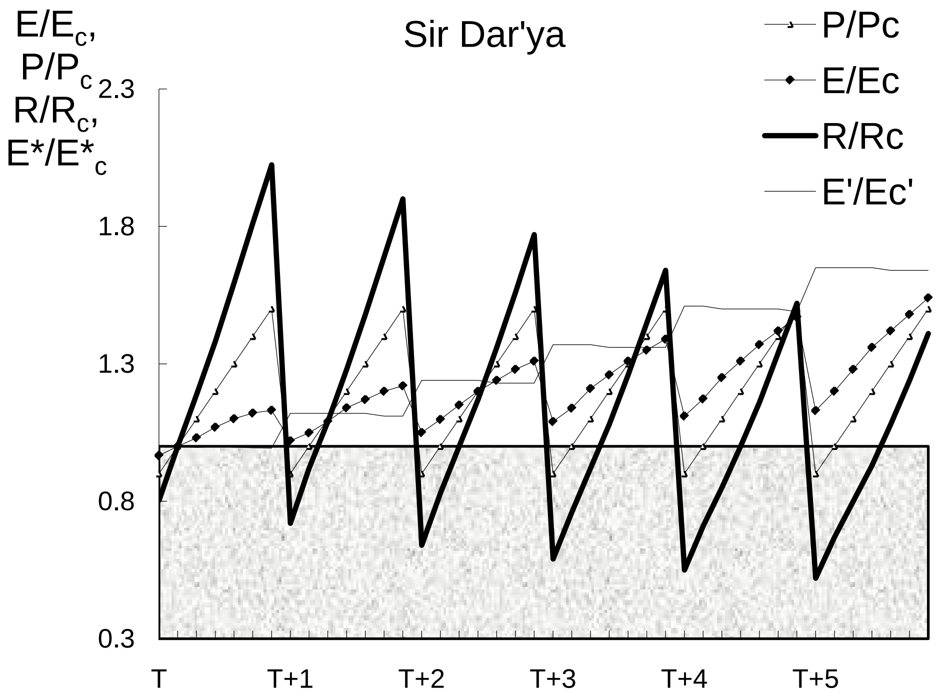
Average computational river runoff , precipitation and potential evaporation for the Tien Shan region during last 50 years



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/R_c), evapotranspiration (E/Ec), potential evaporation (E^*/E^*_c) under predicted changes of air temperature (T_c+d; d=1,2,…5°C) and precipitation (mP_c, 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.