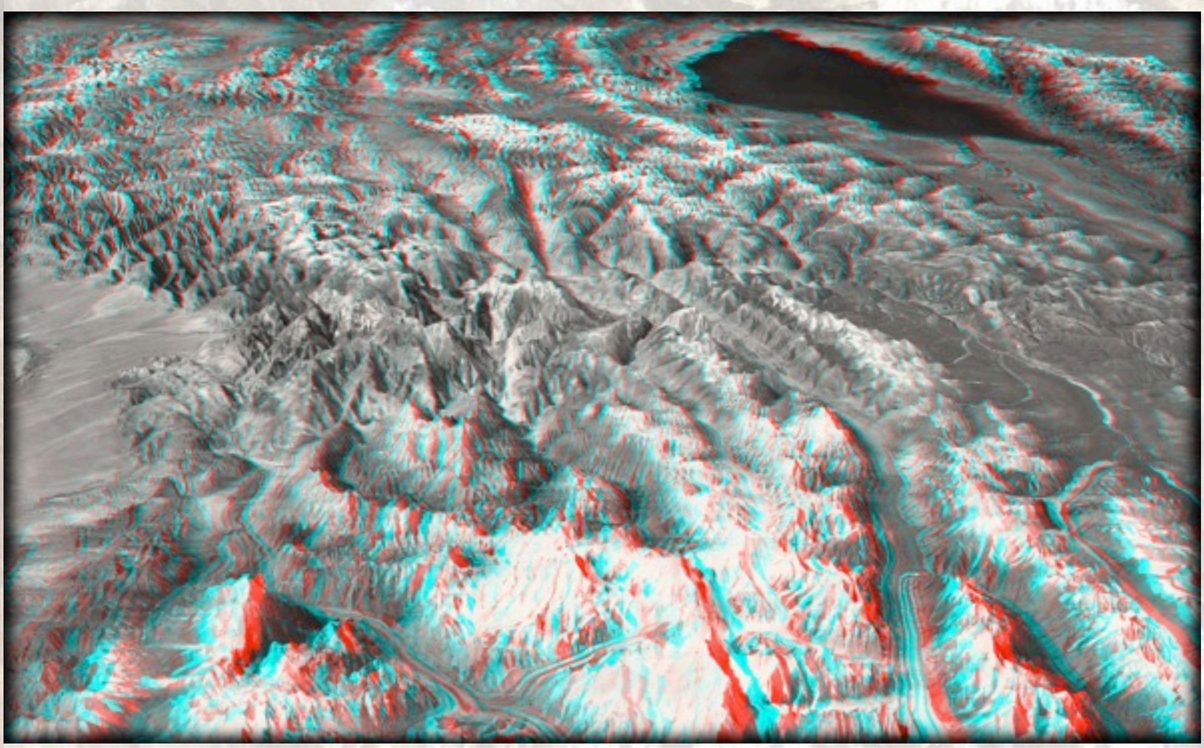
Central Tien Shan Landscape

Water Resources

and

Climate Change Sensitivity

Analysis



For WWF's Asia High Mountains Initiative, funded by USAID

By Nikolai Sindorf

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Sindorf N, *Central Tien Shan Water Resources and Climate Change Sensitivity Analysis*, High Mountains Initiative, WWF/USAID, 2017

Frontpage images are based on Google Earth imagery, 2017

Find updates on: http://thirdpolegeolab.org/#snowy

About the author:

This work has mainly been produced and compiled by Nikolai Sindorf as a consultant on spatial freshwater analysis under the Asia High Mountains Inititiative. This is one of the six landscape analyses under that project.

Nikolai is located in the Mekong region (Vientiane, Laos) where he is working on spatial freshwater vulnerability assessments and environmental analysis. He has experience in the following geographies: Southeast Asia, Central Asia, Egypt, USA, Netherlands

He holds an M.Sc. in Tropical Land- and Water Management of Wageningen University, Netherlands, with specializations in irrigation engineering and geographic information systems.

Specialties: water resources development, conservation hydrology, freshwater climate change sensitivities, environmental flows, sustainable hydropower planning, irrigation, land-water management and geographic information systems

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water, *development*, nature
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"A person cannot step in the same river twice,
for it will neither be with the same flow,
nor be with same character."
after Herakleitos

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Central Tien Shan Landscape

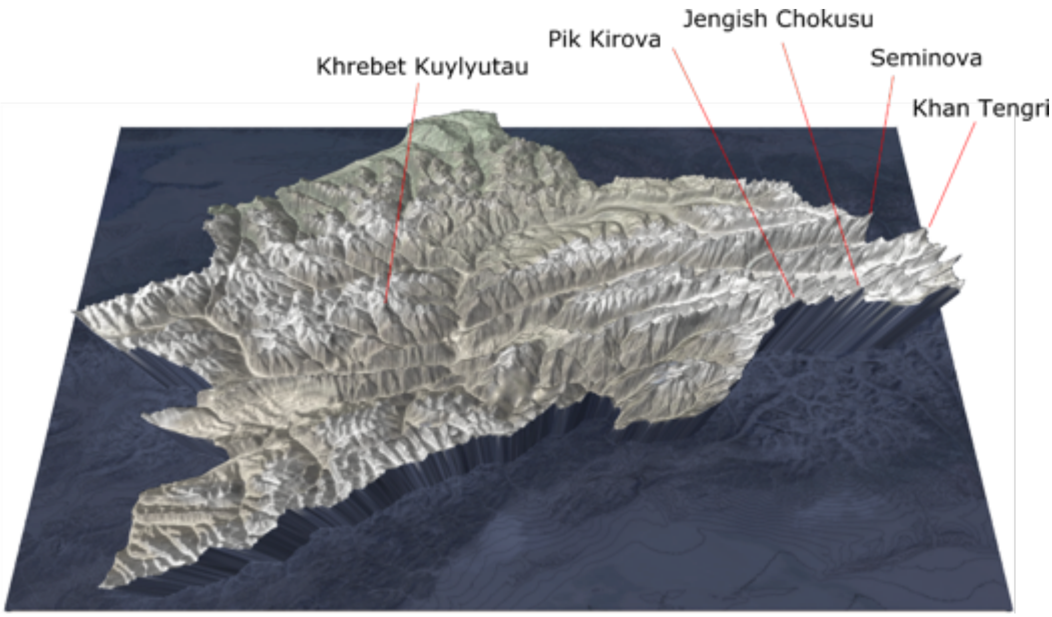
Country: Kyrgyzstan
Size: ~13,000 km^2
Population: ~84,000 (WorldPop 2010)
Highest elevation: ~6,800 MSL
Lowest elevation: ~1,600 MSL

Connections:
North: North Tien Shan (Kazakhstan)
East: Tuomerfeng (China)

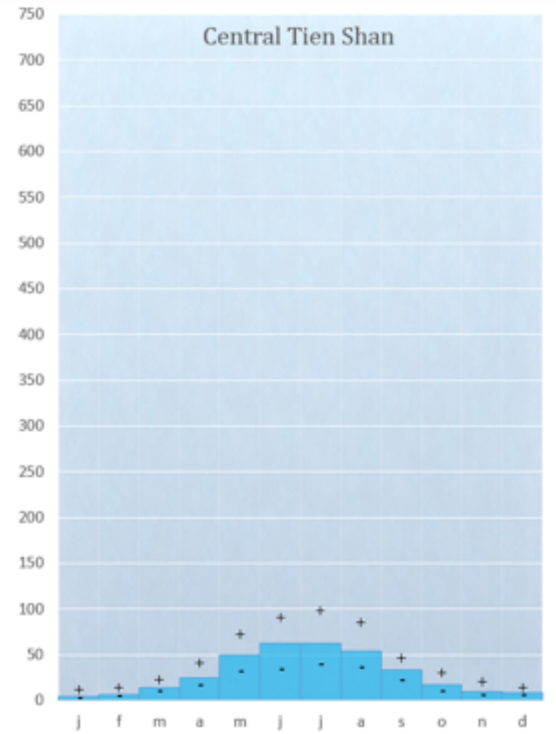
January 2017 version

Overview

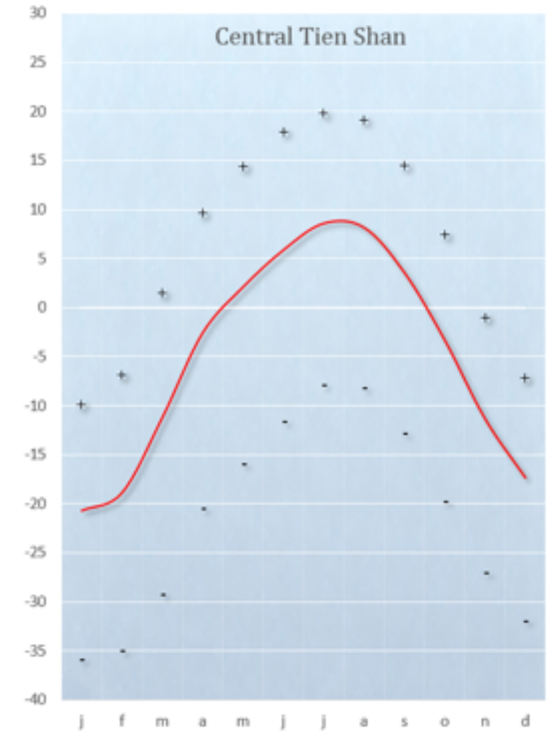

0 10 20 30 40 50 km


Khrebet Kuylyutau
Pik Kirova
Jengish Chokusu
Seminova
Khan Tengri

Basic climate



Historic monthly mean precipitation
in millimeters (WorldClim, 1950 -2000)
+ = highest mean of the landscape
- = lowest mean of the landscape

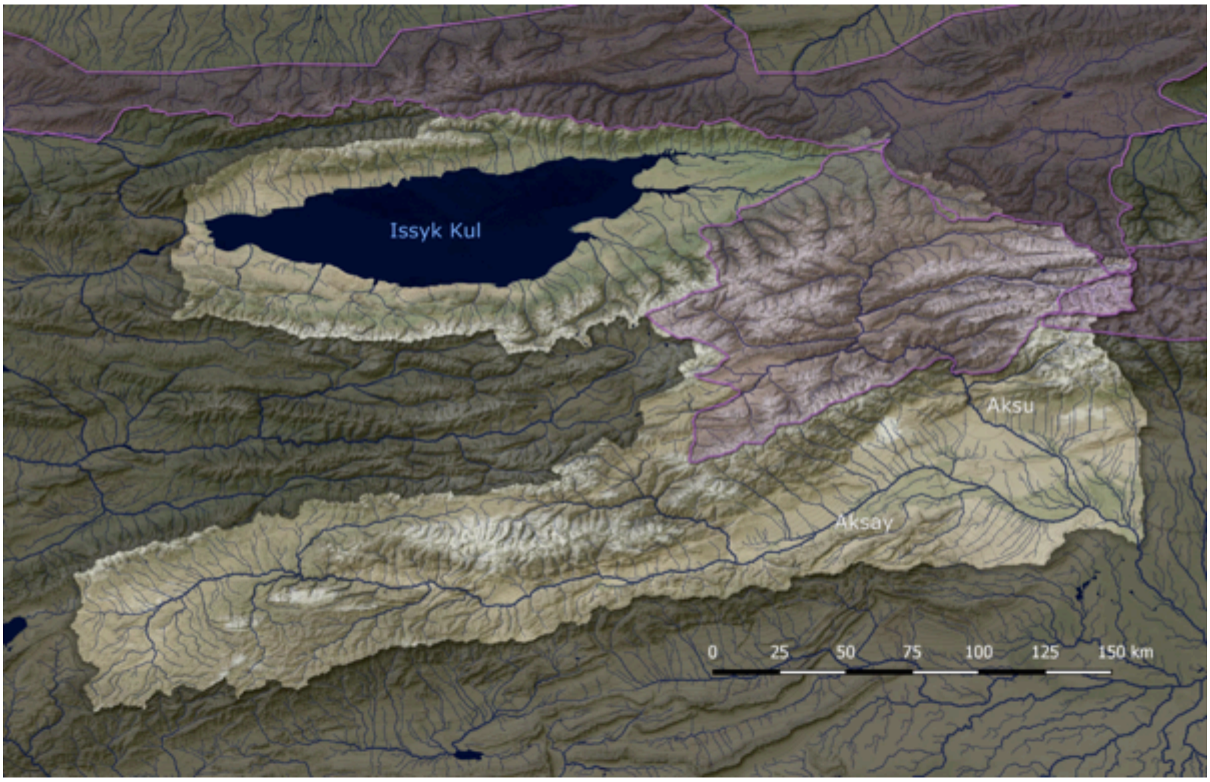


Historic monthly mean temperature
in centigrades (WorldClim, 1950-2000)
+ = highest mean of the landscape
- = lowest mean of the landscape

The rainfall distribution illustrates that the wet season the Central Tien Shan landscape coincides with the summer months, and shows a gradual distribution over the landscape (40- 100 mm in July).

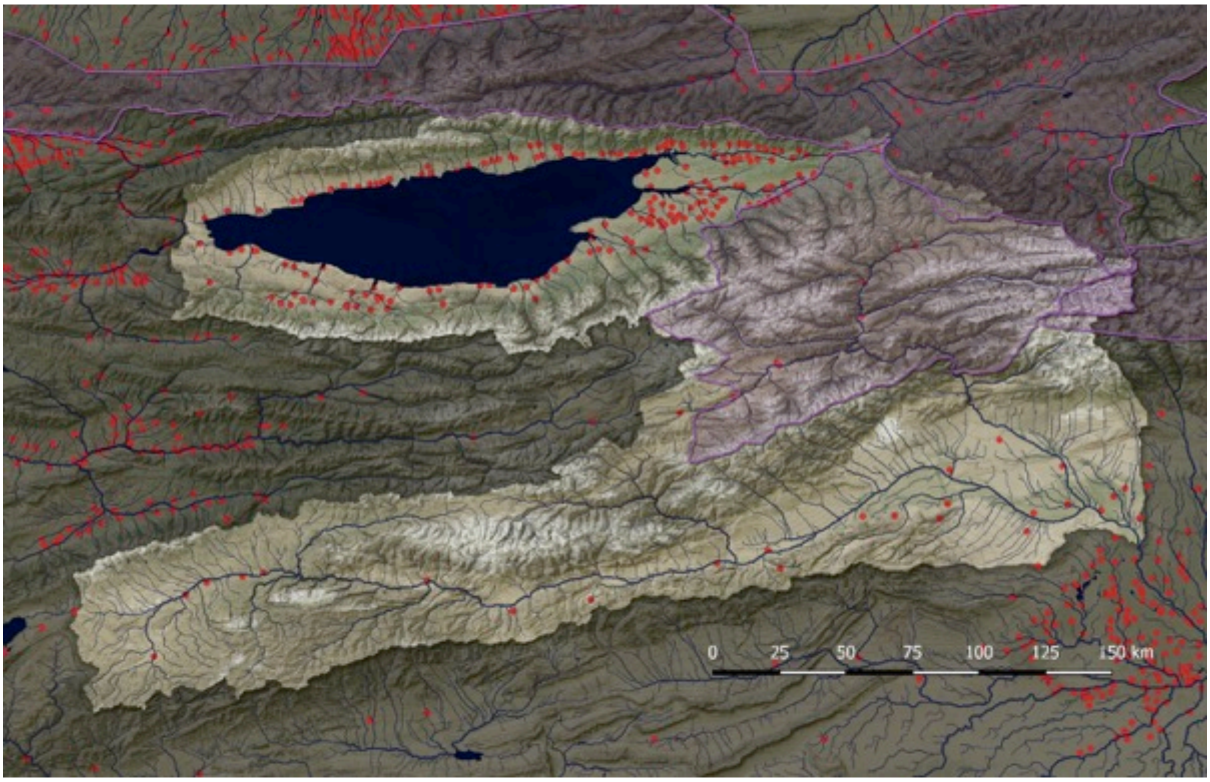
The temperature range is around 25 degrees centigrade throughout the year, it shows a steep rise in mean temperature from February (-20 degrees) to July (9 degrees).

Subbasin context; hydrography



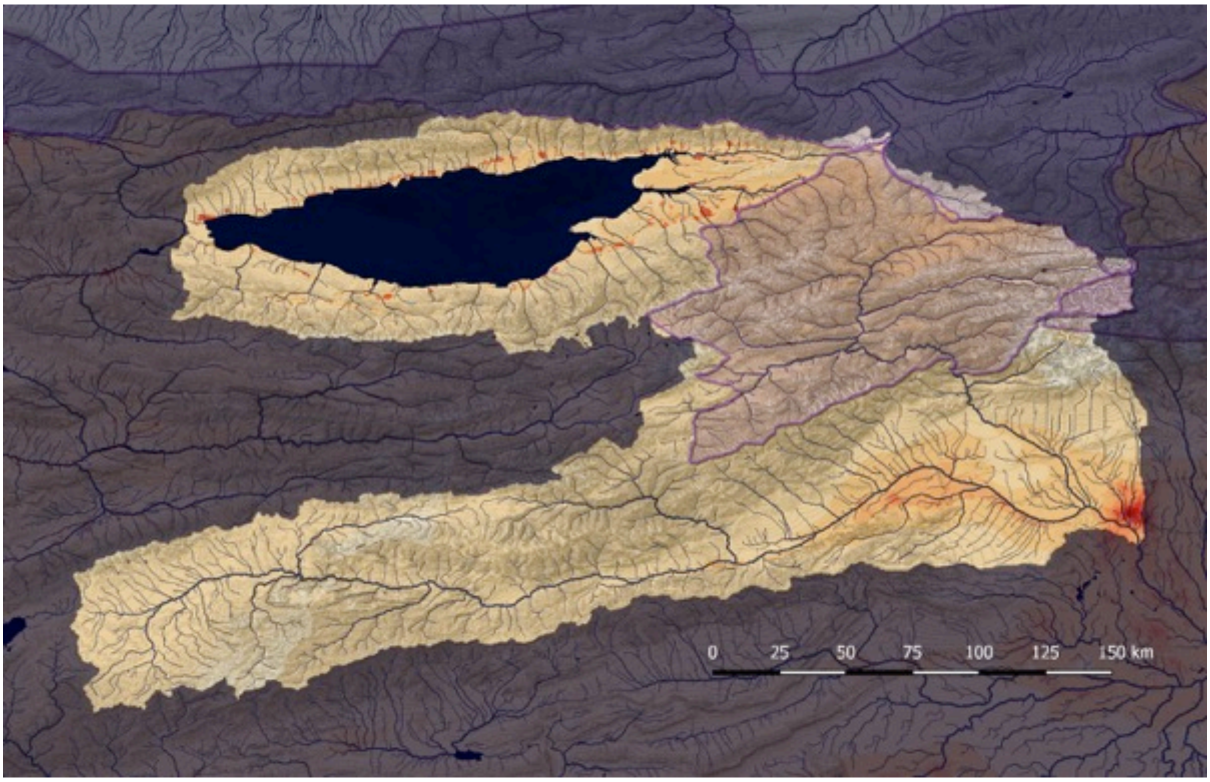
In order to determine the importance of water provision by snowleopard landscapes, it is of importance to consider the landscape's role in its larger subbasin context. For the Central Tien Shan landscape this would include the larger Issyk Kul basin and the Aksay and Aksu rivers, draining into China. The most downstream influence of the landscape's importance in the southern side coincides where Aksay and Aksu rivers join, Aksu city, that is surrounded by irrigated crops.

Subbasin context; human settlements



In the broader subbasin context, the distributions of population densities or human settlements shows that there is little human activity inside the landscape. Most settlements are concentrated around the Issyk Kul lake and directly downstream of the Aksu and Aksay tributaries. In terms of arguments for ecosystem service provision, this map shows that there would be an audience; if the landscape would provide different functions of water provision; the audience (to benefit from water provision) is located directly downstream in/of the landscape. Settlement points are downloaded from geonames.org.

Population density (WorldPop, 2010)



Analysis

In the Issyk Kul basin, population is concentrated around the lake, which makes the lake water balance an important aspect for waterresource planning.

In the Aksu river basin, Aksu city, with a population of around 850,000 people, is located at the confluence of the Aksu and Aksay rivers.

The landscape provides an essential role in water provision to these areas, not only through direct river flows but also through groundwater connections.

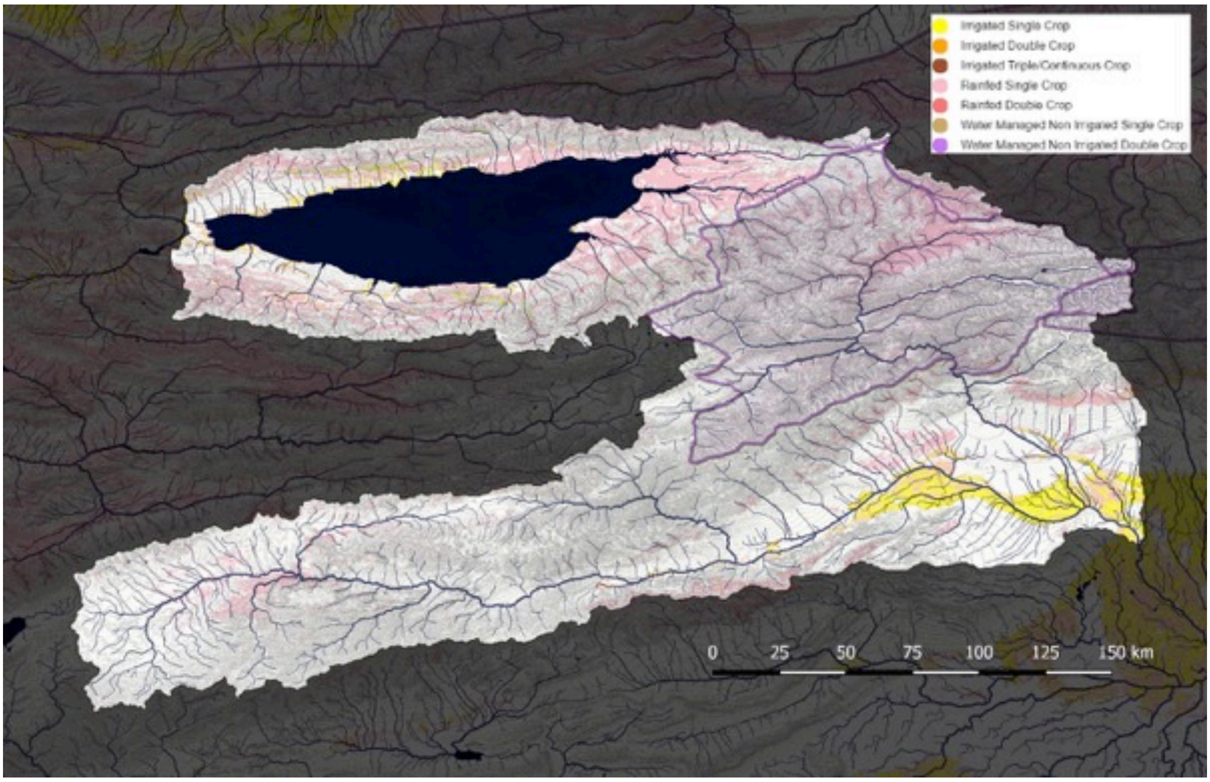
Methodology

This is a map of the WorldPop database, Kyrgyzstan Data.

Data

WorldPop: Tatem AJ, Gething PW, Bhatt S, Weiss D and Pezzulo C (2013) Pilot high resolution poverty maps, University of Southampton/Oxford. http://www.worldpop.org.uk/

Irrigated Area Map Asia (2010)



Analysis

Only rainfed agriculture is taking place inside the landscape in the valleys of all streams and rivers.

In the Issyk Kul basin, irrigated agriculture takes place on the Northern and Southern shores of the lake, but not on rivers draining from the landscape.

In the Aksu river basin, irrigated areas exist along the banks of Aksu and Aksay rivers, just upstream of thein confluence. Water provison from the landscape has an important function to these irrigated areas.

Methodology

From the Irrigated map website:

"*The natural vegetation and croplands exhibit different patterns of seasonal changes. A procedure was developed to utilize the seasonal variations captured in multi-seasonal satellite images to classify the landscape and identifying the irrigated croplands. The mapping was done using 16-day MODIS 250m NDVI composites images (MOD13Q1). A hierarchical classification procedure involving classification techniques and time-series analysis of the NDVI data was followed. Initially, an unsupervised classification using ISODATA algorithm was performed and subsequently, the seasonal patterns of NDVI for each output cluster was analyzed to differentiate various land cover types.*

The developed methodology based on the phenological changes in agriculture areas to map the irrigated and rainfed areas. An image time series created using the MOD13Q1 product of MODIS at 250m spatial resolution has been used to map the phenological stages of crops using advance image processing techniques such as Fourier and Wavelet transformation Analysis of NDVI. The analysis focus was on the quantity of green biomass, annual and semi-annual cycles of vegetation change, and its dependence on the annual rainfall cycle using Canonical Correlation Analysis (CCA) and time lagged regression to separate irrigated and rainfed areas etc.

The agricultural areas were then further categorized into irrigated and rainfed by analyzing the seasonal vegetation trends. Agricultural areas with multiple cropping cycles were identified by analyzing the cyclic nature of vegetation change in agricultural systems. Based on the cropping intensity, agriculture areas were categorized into single, double and continuous crops."

Data

IWMI, http://waterdata.iwmi.org/applications/irri_area/

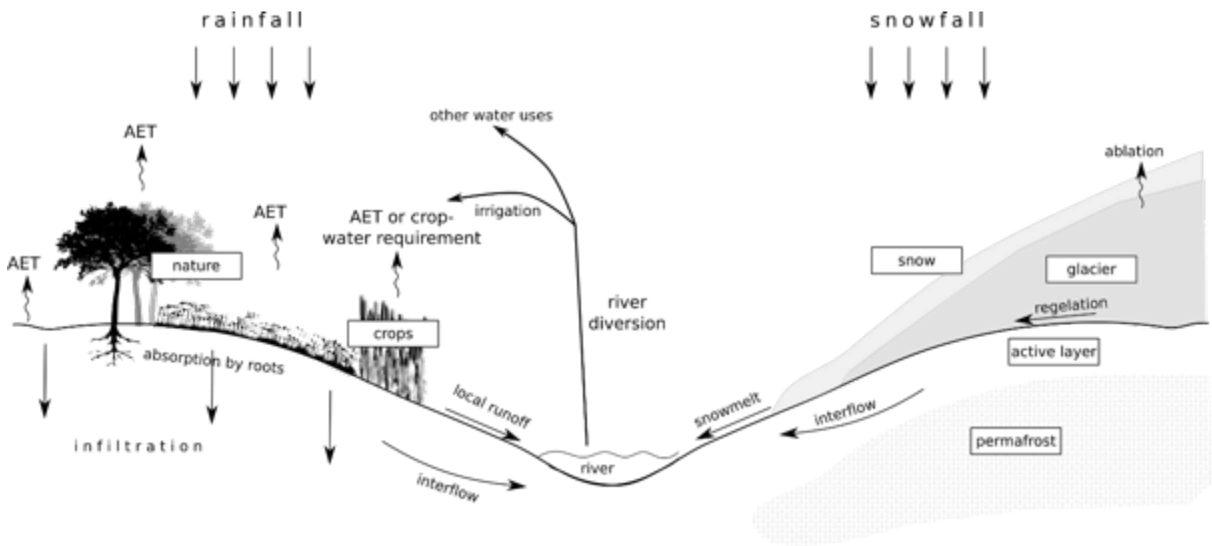
Water provision functions

For the Eastern Nepal landscape four different primary functions are selected that represent different aspects of water provision. These functions are mapped out for the subbasin context, in such a way that it can be assessed what role the snow leopard landscape plays in providing water as an ecosystem service.

- **Local runoff**; is often regarded as the only water provision function. Local runoff is the amount of water in the landscape that ends up in a river or stream and then flows downstream. This is often called “water towers”, since local runoff often starts on the upstream mountain slopes. It can be modelled by looking at rainfall and then taking off the component that is “consumed” by vegetation and soils (actual evapotranspiration). On itself, local runoff has to be considered in monthly timing over a year, and in spatial patterns throughout the landscape. In the larger regional contexts, water provision arguments should not only show positive associations with larger quantities of water, since floods are severe and abundant.
- **Snowmelt**; downstream of mountainous regions, the seasonality of water provision is under direct influence of the annual snowmelt cycles. In many locations, the snowmelt cycle has a different timing than timing of rainfall (or local runoff), often providing essential amounts of water just before, or at the end of the dry season. Under changing temperatures and changing amounts of snow, the change in timing and distribution of snowmelt is essential to be understood; it might lengthen the downstream dry season, but timing might also shift in such a way that it exuberates any flood season. For example when precipitation that historically would have been stored as snowfall in the landscape over the winter, might now runoff and coincide with the flood season.
- **Aridity**; aridity concerns the extent to which water is the limiting factor in vegetation development. Often -in a landscape- local water balances range can from being humid to different levels of aridity; where a chronic level of aridity indicates a trend of desertification. In terms of water provision, it helps to see where in the landscape -or its larger subbasin – there is enough water to sustain vegetation or provide water downstream, and where in the landscape there is a demand for extra water. Aridity is calculated as the amount of precipitation compared to the amount of potential evapotranspiration.
- **River system layout**; through river system layout it can be determined to which extent a location has the capacity to provide water to its downstream. As much as a wet location at the very downstream does not hold much capacity to provide water to the rest of the subbasin, an arid area in the upstream does not hold much capacity to receive water from its upstream.
- **Lakes, wetlands, floodplains**; lakes, wetlands and floodplain are freshwater entities that form a relevant part of the river system layout and the overall water provision context. Recent publications of publically shared databases on surface water and lakes allow more advancedanalysis of a landscape’s surface waters over time.

The water provision functions that are listed below are acknowledged to be of certain importance to water provision and can be mapped out, but at the moment lack essential scientific insights to be incorporated as water provision functions for any of the landscapes.

- **Presence of glaciers**; as much as snowmelt, glaciers provide essential water provision outside of the seasonal precipitation. An important process that lies at the basis of this, is the amount of water that melts off a glacier under pressure (regardless of surface temperature) of the thick ice layers, so-called regelation. Yet modelling quantities of glacial melt has been a challenge; each single glacier act as a reservoir where water melts, or snowfall accumulates, according to many micro factors that underlie the existence of each glacier. In general terms glaciers cannot be considered to be renewable water resources without taking into account at which they accumulate new snowfall, or considering the overall temperature-melt balance through which they have existed for centuries. Under a changing climate, these balances shift, though there is no real rule of thumb for each specific glacier whether it is growing or shrinking.
- **Permafrost coverage**; the presence of permafrost is of direct influence on local hydrology. Season shifts in depths of permafrost are at the base of local hydrology, for example in determining the seasonal water levels in wetlands. Often the permafrost layer is impermeable, and soil-water interaction take place on top of the permafrost layer; the so-called active layer. Naturally the thickness of the active layers is a very local soil characteristic, where issues of soil temperature, aspect, and vegetation cover are all of influence. Any change to this, as well as changes in temperature will all trigger a chain of event, which often leads to permafrost degradation. There is a high correlation between the presence of permafrost, and the larger snow leopard landscape. At the moment there are not enough scientific insights on how locally and region-wide permafrost degradation will be taking place, and whether this would be of influence of snow leopard habitat.
- **Snow cover and freeze line**; the seasonal presence of snow and temperatures below zero centrigrades are an important landscape characteristic that guide seasonality of most of the landscape processes, including hydrology. Under changing temperatures, it is real important how much the freeze line would shift, when and where. Seasonality will change when the freeze line changes, though this change might not always happen linear; a shorter winter will result in earlier spring snowmelt, or maybe also in an extended flood season at the start of winter.
- **Groundwater interactions**; such as recharge, infiltration, interflow or baseflow. Though there is monthly information available on soil-water-balances and recharge flows, this is often too general, too coarse and simplistic to predict the complexity of groundwater interactions inside the landscape, for example in relation with permafrost depths. This study takes an "upstream" approach, any signal in the surface water component will evidentally lead to a change in groundwater interactions, but is is beyond the scope of this study to look further into this



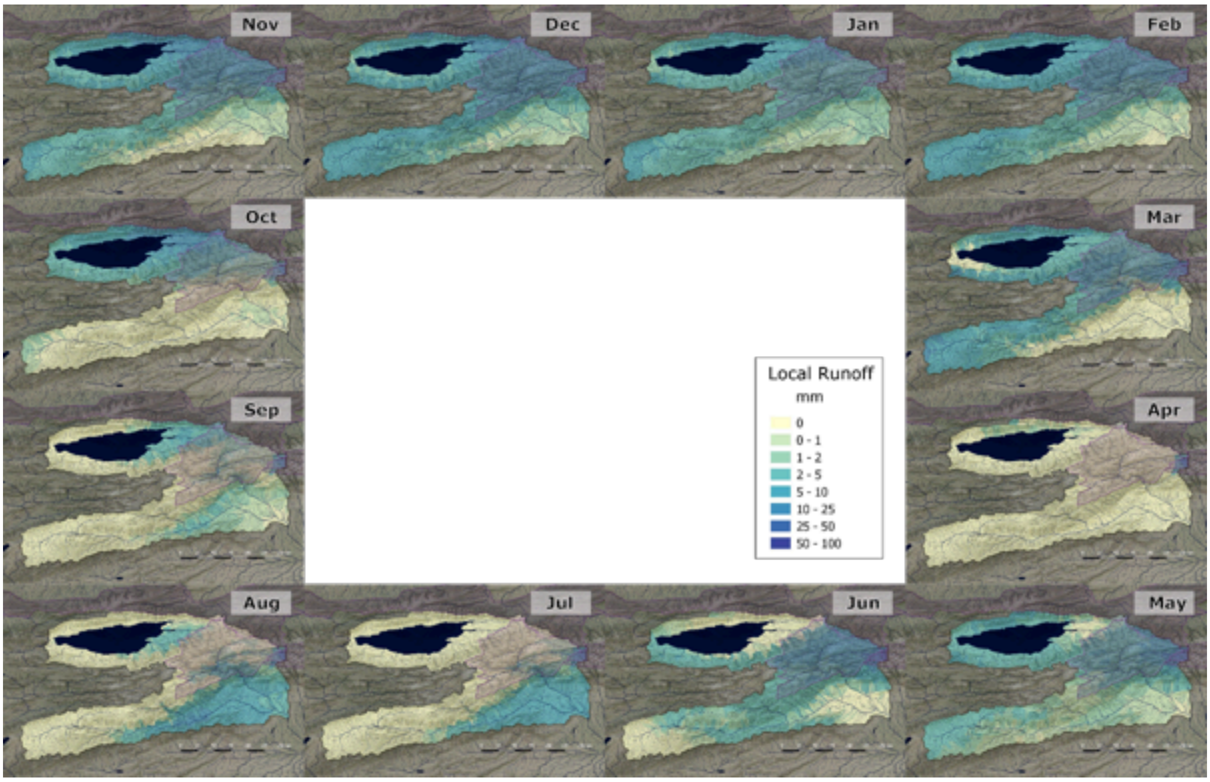
A simplified water balance including the components of rainfall, actual evapotranspiration, and local runoff. To the right: a simplified water balance of the cryosphere, including the components of snowfall, snowmelt, glaciers and permafrost.

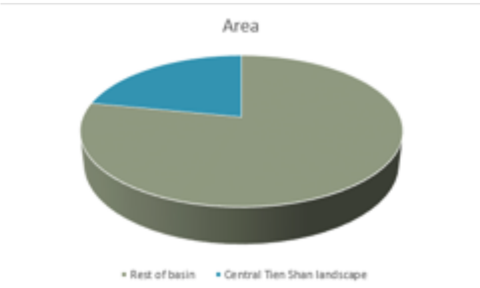
Summarized findings for the Central Tien Shan landscape

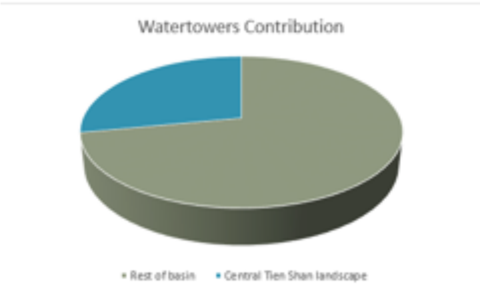
Water Towers/ Local Runoff	
Water provision	only in May and June, the landscape acts as a kind of water towers to its downstream, at the time the downstream ihas significant water demands. Yet during other months of the year, the lansdscape either generates less runoff than its downstream, or downstream water demands are limited
Projected Climate change	The low and high end of -most likely range of projected precipitation change illustrate that there is a high uncertainty on projected change, especially for the month of May the difference between the projections are extreme, ranging from close to zero runoff, to becoming the wettest months of the year and quadrupling the amount of local runoff
Snowmelt	
Water provision	snowmelt is the principle water source to many of the rivers, and peaks in spring (winter snow melts off) and autumn.
Projected Climate change	under temperature rise, these seasons are expected to see the most change in freeze line shift; the amounts and timing of snowmelt will change. Rivers and downstream water use will likely experience a decrease in the reliability of water sources at the peak of their flows.
Aridity	
Water provision	throughout the year, the landscape is more humid than its downstream, while the downstream experiences months of aridity; this indicates that the area can be considered for its relative water provision function in term of aridity
Projected Climate change	The low and high end of the most likely range of projected changes in future annual aridity index show that under lower precipitation, the semi-arid area triples at the expense of humid areas. Under higher preciptation the semi-arid areas will disappear and most of the area will become humid. Either end of this range would have significant impacts on the landscape's vegetation and soil patterns; and the difference between the projections illustrates a high level of uncertainty; this is a landscape characteristic since the water balances in this landscape are relatively fragile.
River system layout	
Water provision	there are a significant downstream parts in both the Issyk Kul and Aksu basins that have their headwaters in the Central Tien Shan landscape and would rely on upstream water provision by the landscape
Projected Climate change	The upstream parts cover the mountains, glaciers, snowfall are sentistive to changes in temperatre and precipitation; this will have impacts on areas downstream that rely on these sources of water. In some cases extra snow and glacial melt will release extra water, this can be put to use, but also result in floods, or droughts.
Glaciers	
Water provision	Most of the glaciers are exposed to three months (July-September)

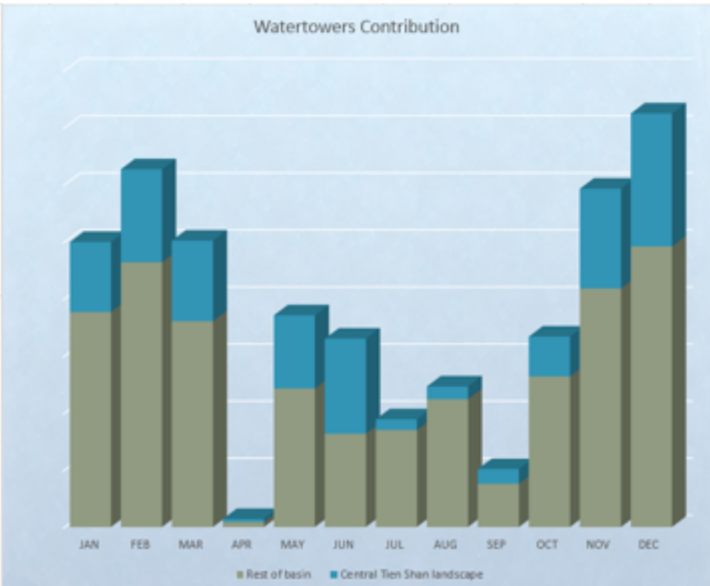
	of thaw (historic freeze line). Continuity principle implies that glaciers can only exist because of the amount of winter snowfall that blankets the glaciers and melts of during summer.
Projected Climate change	Recently it has been observed that glaciers are shrinking under temperature rise, and that extra water is available downstream.
Permafrost	
Water provision	permafrost covers the entire headwaters of the subbasin, and all the headwaters inside the landscape. Permafrost presence is a master variable to local hydrology, especially since many of the downstream rivers have a large component or (groundwater-) base flow. The current permafrost database lacks relevant information on typologies which would be essential to assess their role to local hydrology
Projected Climate change	any permanent change will have direct impact on water provision to the downstream, melting of permafrost will result in landslides and sinking groundwater levels, among other impacts
Snow cover and freeze line	
Water provision	Snowcover occurs througout the year in the landscape accumulates and covers most of the landscape during winter and remains in summer on many of the range's the mountain tops.
Projected Climate change	Shifts in freeze line do not occur in the winter season because the temperatures are too low for that. In the summer season the shift in freeze line amount to hundreds of meters to kilometers, but around snow covered mountain tops; so a severe impact on snow and glacial melt-off is likely.
Lakes, wetlands and floodplains	
Water provision	the northern parts of the landscape drain into Issyk Kul, which is a Ramsar site; which means it is a globally important wetland. Floodplains of Aksu river reach into the landscape. In total 0.3 % of the landscape area is covered by surface water, mainly concentrated along the floodplains. There are many smaller glacial lakes, and some of them pose a risk as GLOFS.
Projected Climate change	there are many smaller lakes, downstream of glacier and snow-fields. The database on surface water detects many of these smaller lakes, though there is not evident pattern of change between 1984-2015. Most of the open surface water is located in the 2,500-3,500 elevation belt, peaking between 2,500 and 3,000 msl. where most of the glacial flieds are located. This implies that the open water entities are mainly glacial-fed lakes and floodplains.

Water provision functions; water towers (local runoff)









Analysis

The color scheme of this map is adjusted (compared to other water tower maps of other landscapes) in order to highlight the specific spatial and seasonal differences; local runoff components are relatively low, compared with other landscapes. While the methodology maps local runoff during the winter months; in reality the precipitation component often falls as snow and accumulates in the landscape to melt off during spring; after itfalls, often it is transported over the landsurface due to winds, before it melts off. This local runoff model is therefore not the best prediction of snowfall and snowmelt; so, these are discussed in other maps.

Subbasin context

The landscape acts as a belt between the northern Issyk Kull basin and the southern Aksu and Aksay river basins. In winter due to low temperatures demands A quick rise in temperature in spring, likely results in high plant productivity in April, but less local runoff originating from the landscape. Only in the months of May and June, when downstream water demands are significant, the landscape acts as part of the Tien Shan water towers. Yet in July to September, when water demands are highest over the year, the landscape is much drier than its downstream.

Landscape context

Inside the landscape, the eastern parts seem to generate more local runoff than the western parts. Runoff season starts earlier and ends later in the eastern parts, while the amounts of runoff also seem to be higher.

Methodology

Local runoff is the difference between monthly precipitation (P) and actual evapotranspiration (AET). Monthly precipitation and AET are downloaded and, through a simple GIS command, summarized by their watershed 'mean', using HydroBASINS level 12 watersheds. The mean values are multiplied by each of the watershed area in order to convert from millimetres to cubic meters. Then these values are subtracted (P – AET); local runoff values that are less than zero are displayed and flagged as being zero. Inside the subbasin, those watersheds that drain the snow leopard landscape are flagged. See download links below.

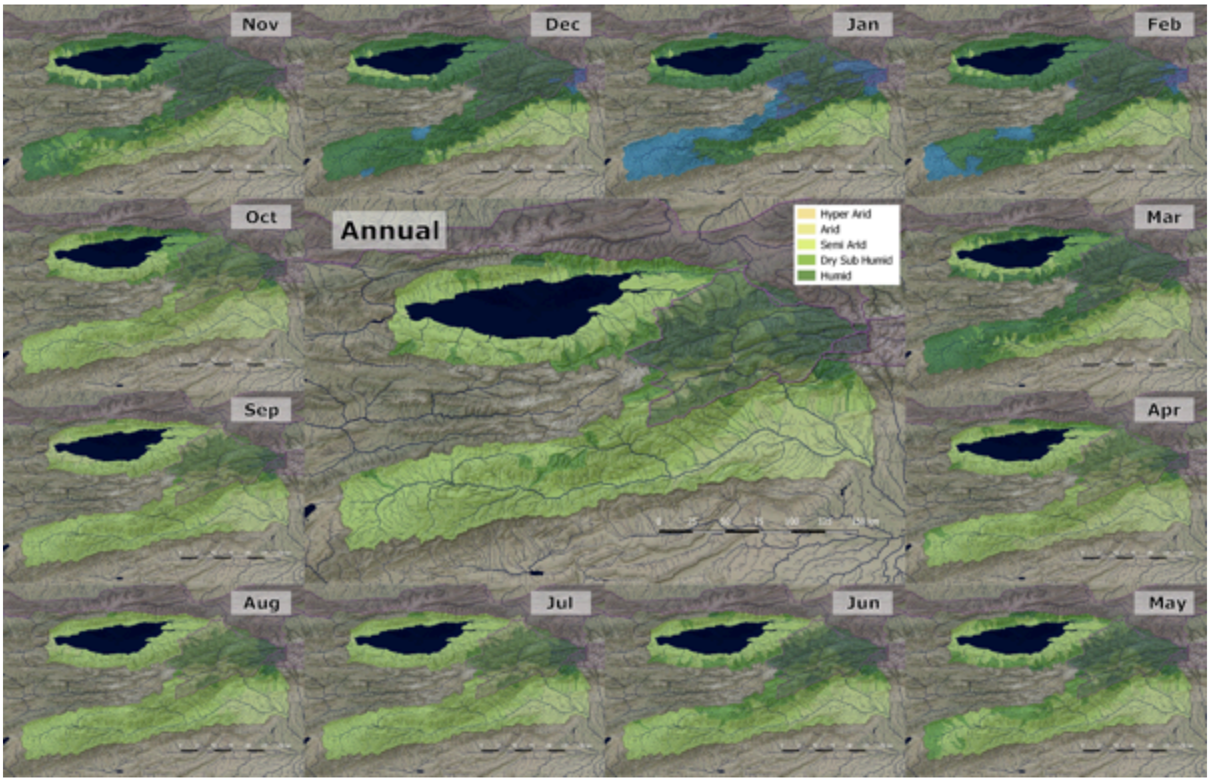
Data

Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Trabucco, A., and Zomer, R.J. 2010. Global Soil Water Balance Geospatial Database. CGIAR Consortium for Spatial Information. Published online, available from the CGIAR-CSI GeoPortal at: http://www.cgiar-csi.org

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; aridity and humidity



Analysis

The humidity in the winter months is mainly a function of the very limited (close to zero) potential evapotranspiration, which means that none of the local soils and vegetation have a demand for rainfall. Yet throughout the year, the most humid parts of the larger subbasin are located inside the landscape. This indicates two patterns;

- water demands of soils and vegetation inside the upstream landscape are met,
- the downstream areas (especially the southern lands) have a demand for extra water throughout the year.

In this case it indicates an important relation between the wetter landscape in the upstream and the more arid areas directly downstream.

Methodology

Aridity measures to which extent precipitation (P) is the limiting factor in water demands for vegetation growth (potential evapotranspiration, PET). Monthly precipitation and PET are downloaded and, through a simple GIS command, summarized by their watershed 'mean', using HydroBASINS level 12 watersheds. Then these values are divided (P/PET) and classified according to the following aridity classes:

Aridity (P/PET)	
< 0.03	Hyper arid
0.03 – 0.2	Arid
0.2 – 0.5	Semi arid
0.5 – 0.65	Dry sub humid
0.65 <	Humid

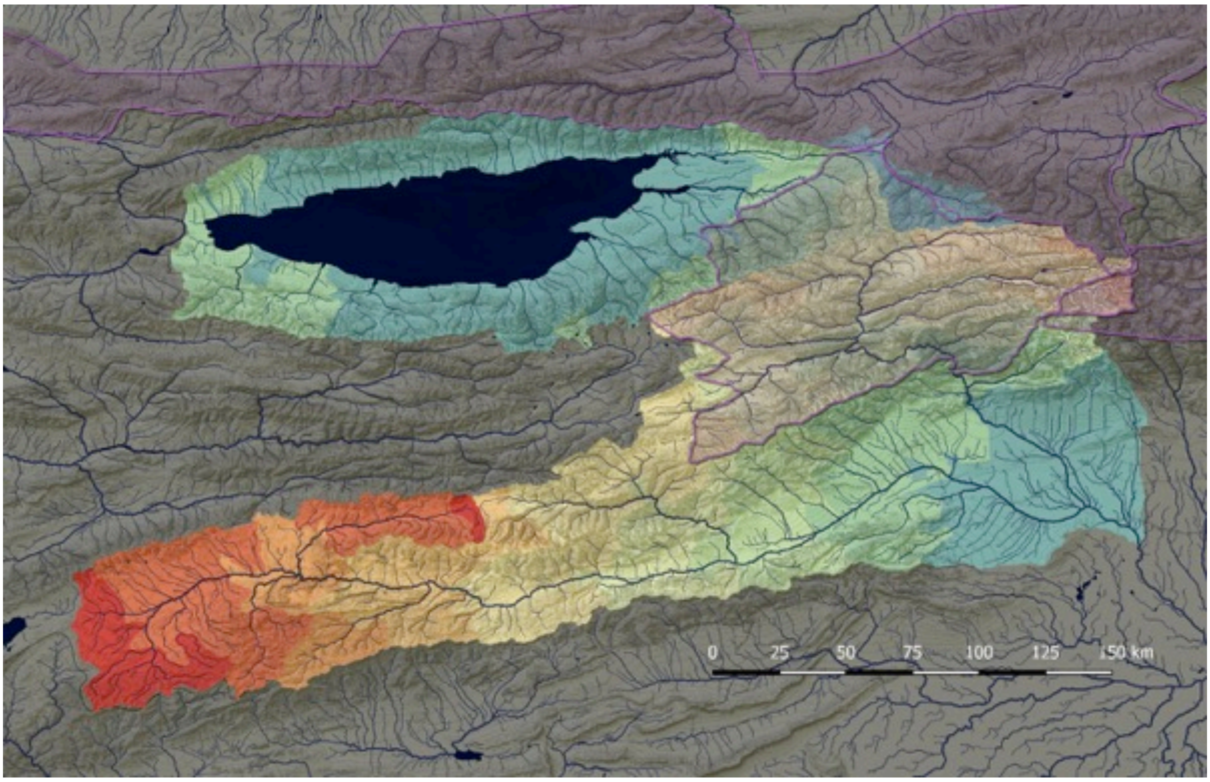
Data

Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Zomer RJ, Trabucco A, Bossio DA, van Straaten O, Verchot LV, 2008. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. Agric. Ecosystems and Envir. 126: 67-80.

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; river system layout



Analysis

Subbasin context

The river layout function helps to visualize where in the river system important features are located; in the upstream or downstream. For water provision and ecosystem service arguments, it is important that there is some upstream-downstream connectivity.

The river system layout function can best be understood in relative terms; what is more upstream and therefore has better opportunity to provide water to its downstream. In that perspective, there are a significant downstream parts in both the Issyk Kul and Aksu basins that have their headwaters in the Central Tien Shan.

For the Issyk Kul basin, the landscape covers the largest and most-upstream parts. Though the lake also receives water from the many smaller streams that surround it.

The most southwestern parts (Aksay basin) of this subbasin were added because there is the suggestion to expand the landscape, including more of the southwestern range.

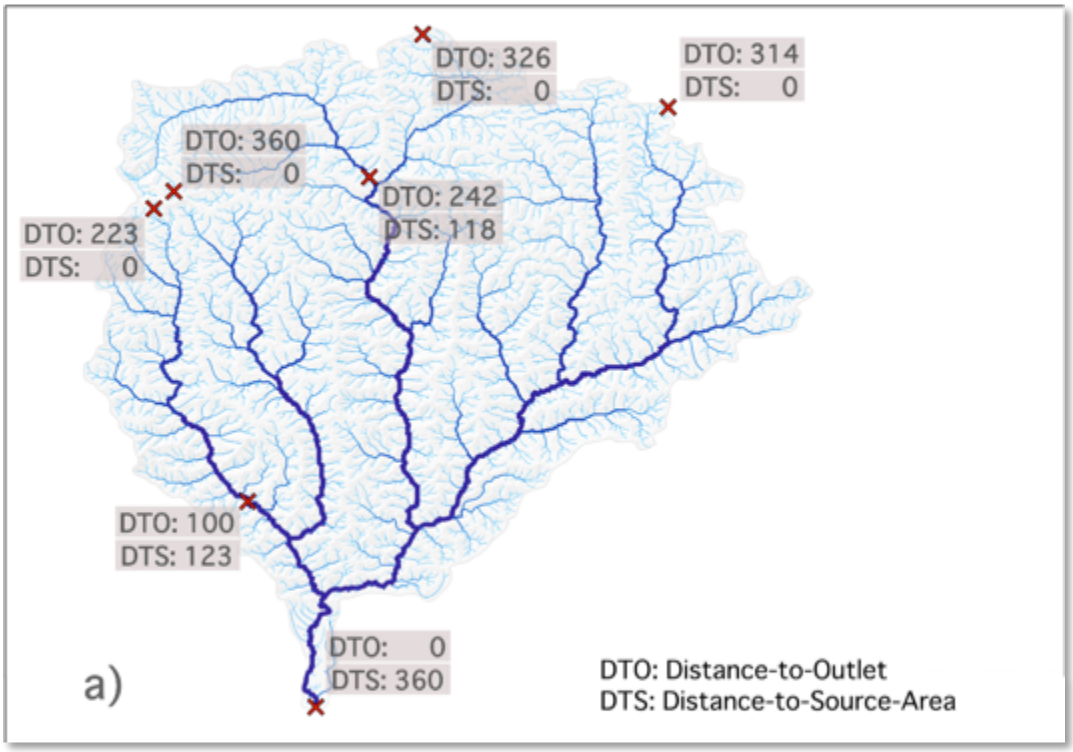
Landscape context

The southern and the eastern boundaries of the landscape coincide with the Chinese boundaries, which do not always follow river basin boundaries.

Methodology

HydroSHEDS 15 drainage directions are used to calculate flow distances; first local flow distances (the distance that a virtual stream flows over each individual cells) and then calculating the distance to source area and distance to outlet. These functions work as follows:

- ***distance to source*** (DTS) areas measures for any location inside a river basin, along the stream, the distance to the most upstream source,
- ***distance to outlet*** (DTO) measures for any location inside a predefined river basin, the point furthest downstream, i.e. the point where the entire basin drains to,
- ***longest stream***, the maximum values DTS and DTO of a river basin are identical and measure the longest stream in the basin.



These three variable are calculated into a single function, and summarized (mean) for each level-12 watershed:

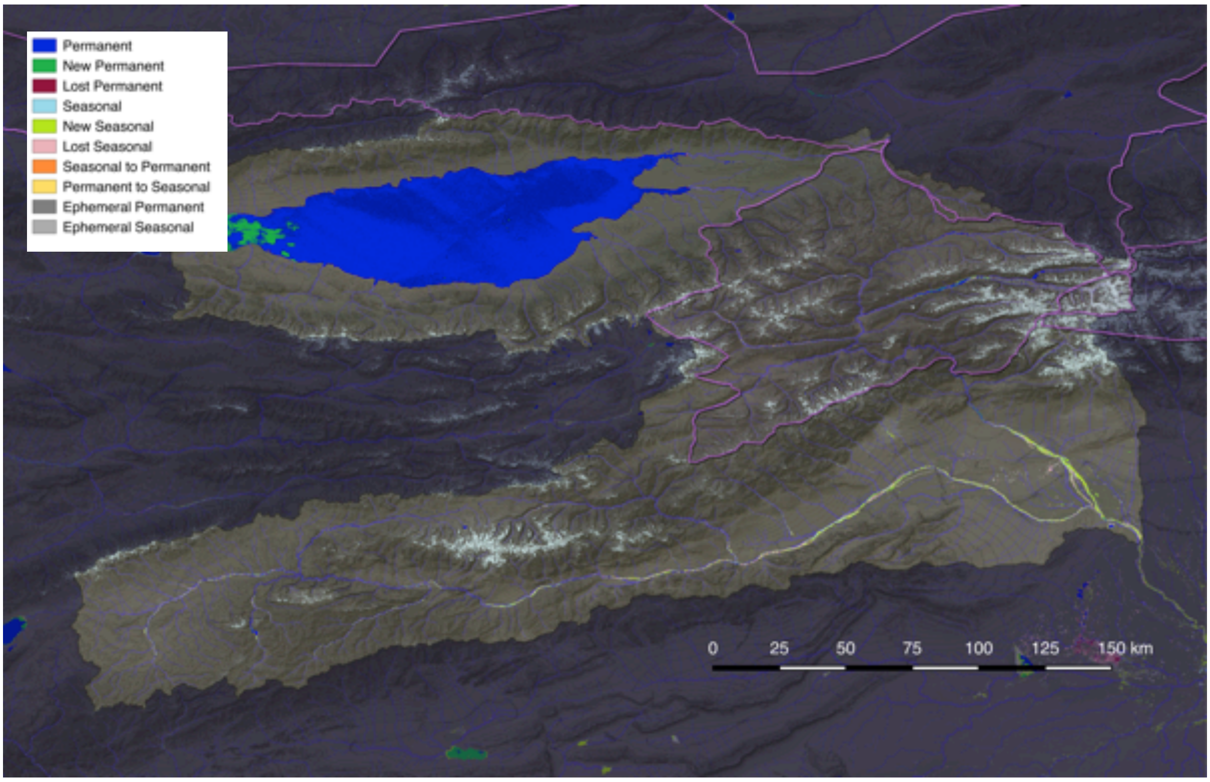
$$headwater\ function\ = \frac{DTO}{longest\ stream} \times \frac{DTO}{DTO + DTS}$$

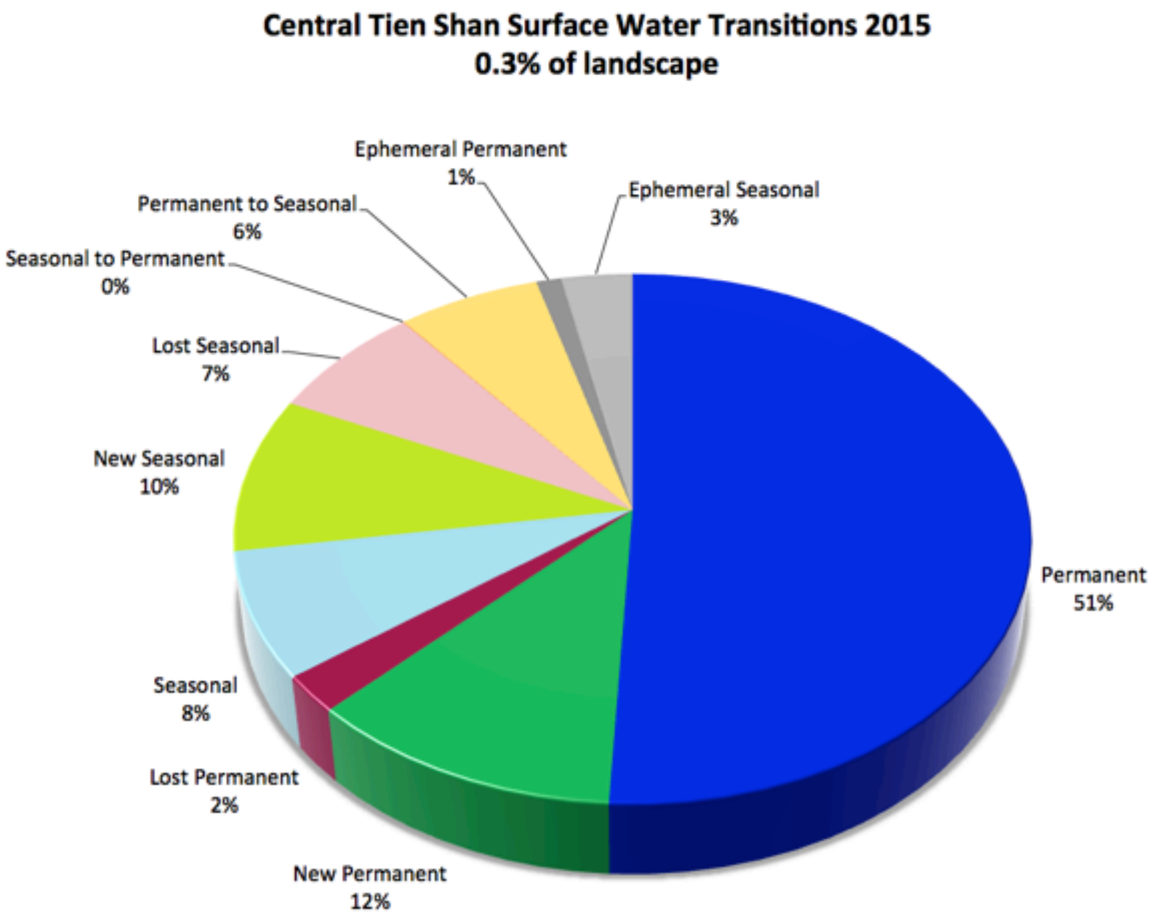
Data

HydroSHEDS 15s drainage directions; Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. Data is available at www.hydrosheds.org

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; Global surface water transitions (1984-2015)





Overview

The maps show two relevant water covers *in the wider subbasin*;

- Issyk Kul lake (downstream of the landscape)
- Floodplains in the Aksu/Aksay basin

From Wikipedia:

"Issyk-Kul is an endorheic lake in the northern Tian Shan mountains in eastern Kyrgyzstan. It is the tenth largest lake in the world by volume (though not in surface area), and the second largest saline lake after the Caspian Sea. Issyk-Kul means "warm lake" in the Kyrgyz language; although it is surrounded by snow-capped peaks, it never freezes."

The lake is a Ramsar site of globally significant biodiversity (Ramsar Site RDB Code 2KG001) and forms part of the Issyk-Kul Biosphere Reserve.

Inside the landscape; according to the most recent map of global surface water (Pekel, 2016) only 0.3% is classified as open surface water; it can therefore hardly be identified in the above map. The following transitions occurred between 1984 and 2015:

- 63% of the open water surface was *stable* (permanent 51 %, seasonal 8 %, ephemeral 4%)
- 9 % of the open water surface *disappeared* (permanent 2%, seasonal 7 %)
- 22 % classified as *new* surface water (permanent 12%, seasonal 12 %)
- while 6% of all open water surface *changed from permanent to seasonal*.

These shifts can be explained because most of the open surface waters are located around the very active floodplains that are fed mainly by snow and glacial melt.

The global HydroLAKES database (Messager, 2016) detects six smaller lakes inside the landscape:

Name	Surface Area (km^2)	Shoreline (km)	Volume (10^6 m^3)	Average Depth (m)	Elevation (m)	Upstream Area (km^2)
unknown	0.13	2	0.72	5.8	3371	2.7
unknown	0.47	3.09	4.63	9.9	2919	76.8
unknown	0.11	1.45	0.5	4.6	3448	2.2
unknown	0.12	1.4	0.69	6	3677	4
unknown	0.11	1.42	0.68	6.4	3469	1.1
Ala Kul	1.01	6.32	17.44	17.2	3519	12.2

In both the surface water database and Google Earth, many smaller lakes can be identified, often snow- or glacial melt-based, and many of these pose a risk of GLOFS. The surface water database does not register a significant or systemic increase or change to these lakes, though more in-depth study would lead to valuable insights. One recommendation would be to create a database of smaller lakes with names, simple characteristics (location, area, elevation) in order to monitor patterns of change.

Methodology

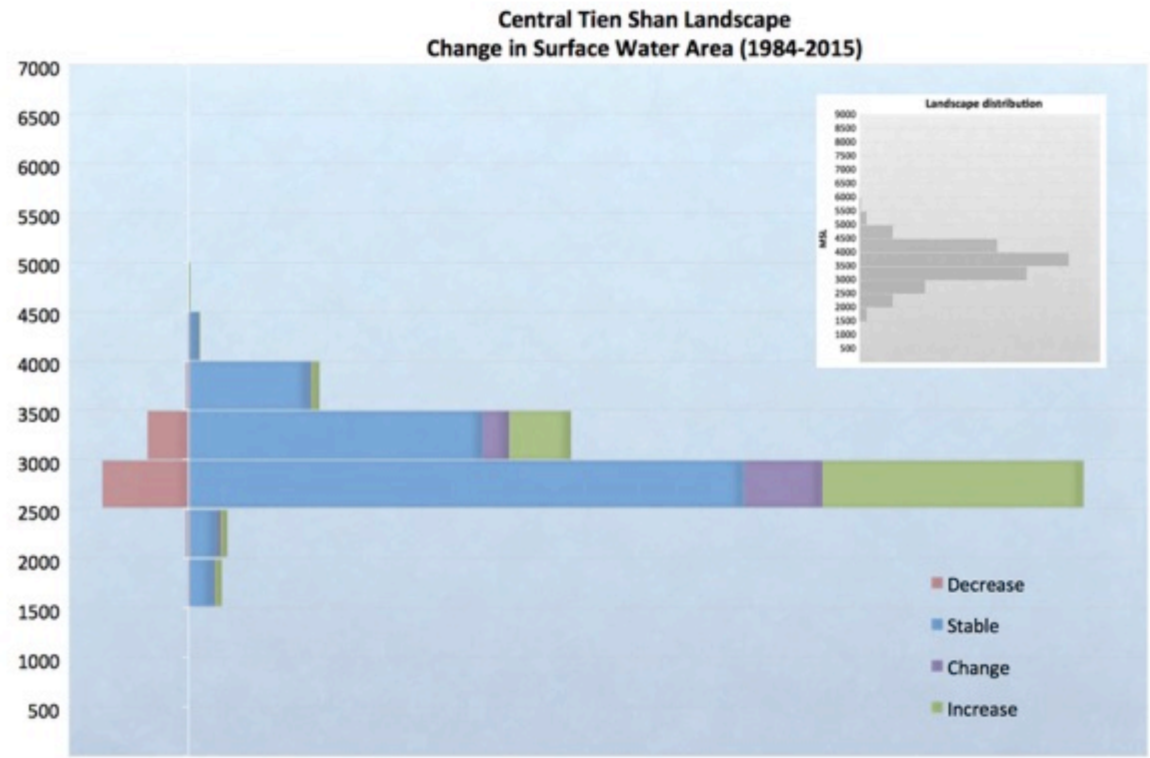
The the map of global surface water and its long-term changes, is a recent high-resolution product (Pekel, 2016). It contains at least 6 different datasets, and allows time-lapse analysis from 1984-2015, which coincides with Landsat coverage. From the https://global-surface-water.appspot.com/ website:

"The Water Transitions map documents changes in water state between the first year and the last year of observation. It documents:

- *New permanent water surfaces (i.e. conversion of a no water place into a permanent water place.)*
- *Unchanging permanent water surfaces*
- *Lost permanent water surfaces (i.e. conversion of a permanent water place into a no water place)*
- *New seasonal water surfaces (i.e. conversion of a no water place into a seasonal water place)*
- *Unchanging seasonal water surfaces*
- *Lost seasonal water surfaces (i.e. conversion of a seasonal water place into a no water place)*
- *Conversion of permanent water into seasonal water*
- *Conversion of seasonal water into permanent water*
- *Ephemeral permanent water (i.e. no water places replaced by permanent water that subsequently disappeared within the observation period)*
- *Ephemeral seasonal water (i.e. no water places replaced by seasonal water that subsequently disappeared within the observation period)*

Temporal profiles recording the full history of each pixel are provided. These allow us to define on a monthly basis the water presence or absence (and also the absence of observation) throughout the archive. Using the profiles it is possible to identify specific months/years in which conditions changed, e.g. the date of filing of a new dam, or the month/year in which a lake disappeared. In addition, profiles documenting the seasonality (and possible transition of seasonality) are provided. These profiles allows to discriminate between occurrence changes resulting from intra and inter-annual variability or resulting from appearance or disappearance of seasonal or permanent water surfaces."

The lakes in the HydroLAKES have been checked on Google Earth (2017) for names.



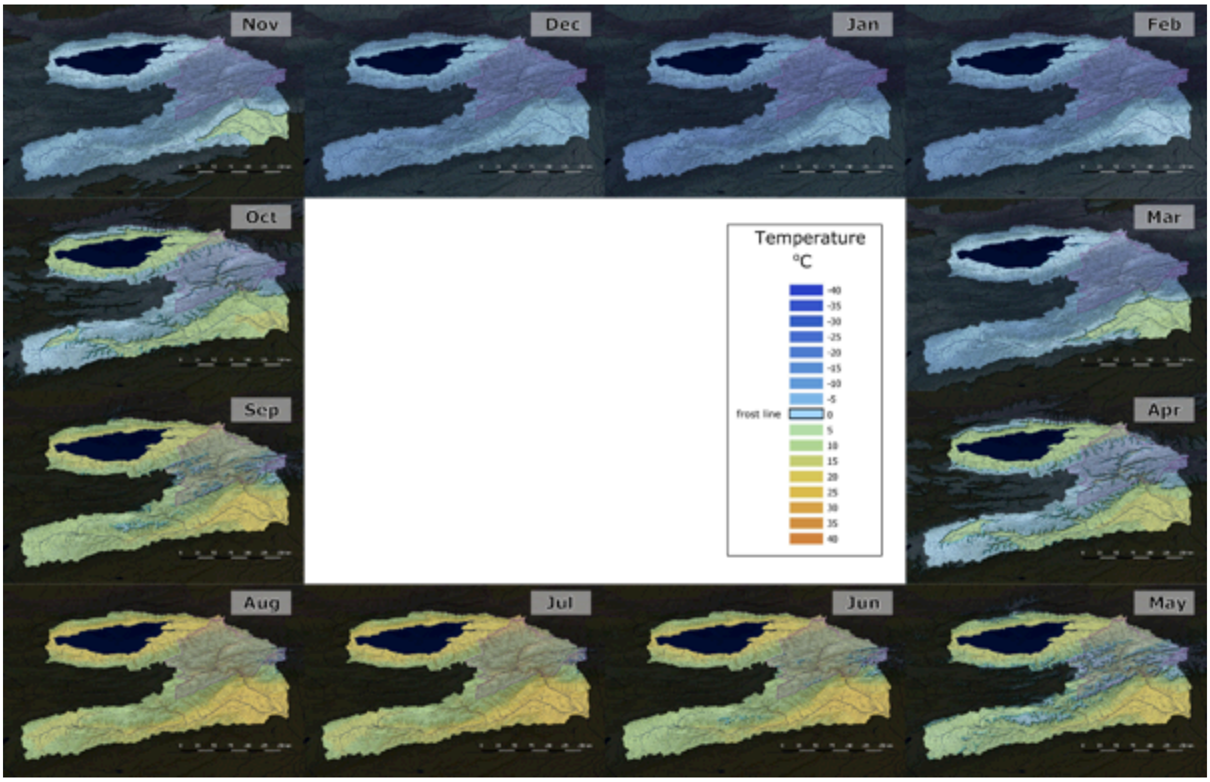
Most of the open surface water is located in the 2,500-3,500 elevation belt, peaking between 2,500 and 3,000 msl. This while the landscape itself is peaking around 3,500-4,000 msl (see inset), where most of the glacial flieds are located. This implies that the open water entities are mainly glacial-fed lakes and floodplains. The increase over the 1984-2015 perion might indicate that the glaciers are melting off leading to expanded glacial lakes. The graph only displays surface water *areas*, and *not volumes* of water.

Data

Pekel, J.-F., Cottam, A., Gorelick, N. & Belward, A. S, *High-resolution mapping of global surface water and its long-term changes,* Nature **540**, 418–422 (2016). https://global-surface-water.appspot.com/

Messager, M.L., Lehner, B., Grill, G., Nedeva, I., Schmitt, O. (2016): *Estimating the volume and age of water stored in global lakes using a geo-statistical approach.* Nature Communications: 13603. doi: 10.1038/ncomms13603. Data is available at www.hydrosheds.org.

Water provision functions; freeze line



Analysis

Subbasin context

The landscape covers the coldest parts of the larger subbasin:

- it contains those areas that freeze the earliest in autumn, and melt-off latest in spring
- it contains those areas that are coldest throughout the year.

During the winter months, temperatures in the entire subbasins drop far below zero, even under dramatic temperature rise, these areas will remain frozen over the winter months; though a shift in overall freezing period might be possible.

The landscape acts as the larger subbasins' source related to the freeze/thaw cycle, and will therefore be very influential in subbasin changes due to temperature rise.

The minimum extent of the freezeline lasts for three months (June-August), and only covers the mountain range in the very east of the landscape (apart from some small mountaintops).

Lake Issyk Kul does not freeze over during the winter.

Landscape context

Inside the landscape, the northern slopes –those draining into Issyk Kul- show a shorter winter than the southern slopes; this difference can be observed both in May and September. Due to its size and depth, the Issyk Kul is likely to create a very distinct climatology in its basin, where position relative to the lake is very important to local climate.

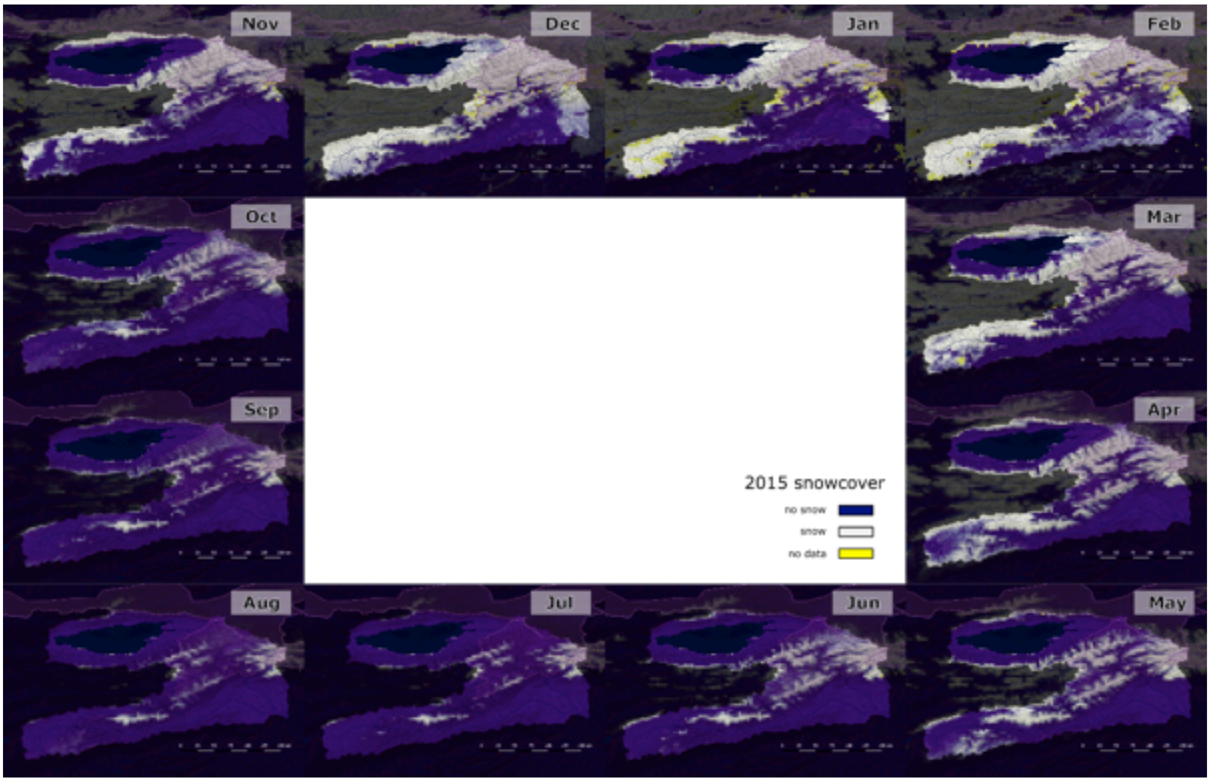
Methodology

This is a map of WorldClim mean monthly temperatures at 30s resolution with the freeze line highlighted.

Data

Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Water provision functions; snow cover (2015)



Analysis

Subbasin context

This snowcover database is a product of satellite image interpretation, part of the MODIS library. It is therefore based on observation and not on modelling. For each 0.05 x 0.05 degree cell, the percentage of monthly snow cover is reported. Due to some of the data artefacts (no data, e.g. through cloud cover), it is difficult to calculate inter-annual means, hence only the snow cover for the year 2015 is mapped out.

The monthly snow cover in winter covers around 3/4th of the subbasin; in summer the snow cover remains on top of the mountain ranges. The freezeline analysis –in comparison- illustrates that many of the snow covered areas are exposed to melting temperatures over three months of summer (June-August). Where snowpack still remains after the summer, it must have been so thick that not all of it could melt off, it is likely that these areas show a high coincidence with existing glaciers.

The map only shows snow cover as a landscape attribute, it does not provide information on the amounts of snow, snow depth, or timing of snowmelt. The next map goes into more detail on snowmelt amounts and timing.

Landscape context

Inside the landscape, mountaintops are covered by snow, but deeper valleys remain without snowcover throughout the year. The deepest valleys are located in the southern parts of the landscape, mainly in the Aksu subbasin. The northern parts of the landscape, draining into the Issyk Kul lake, show a much higher density of snowcover.

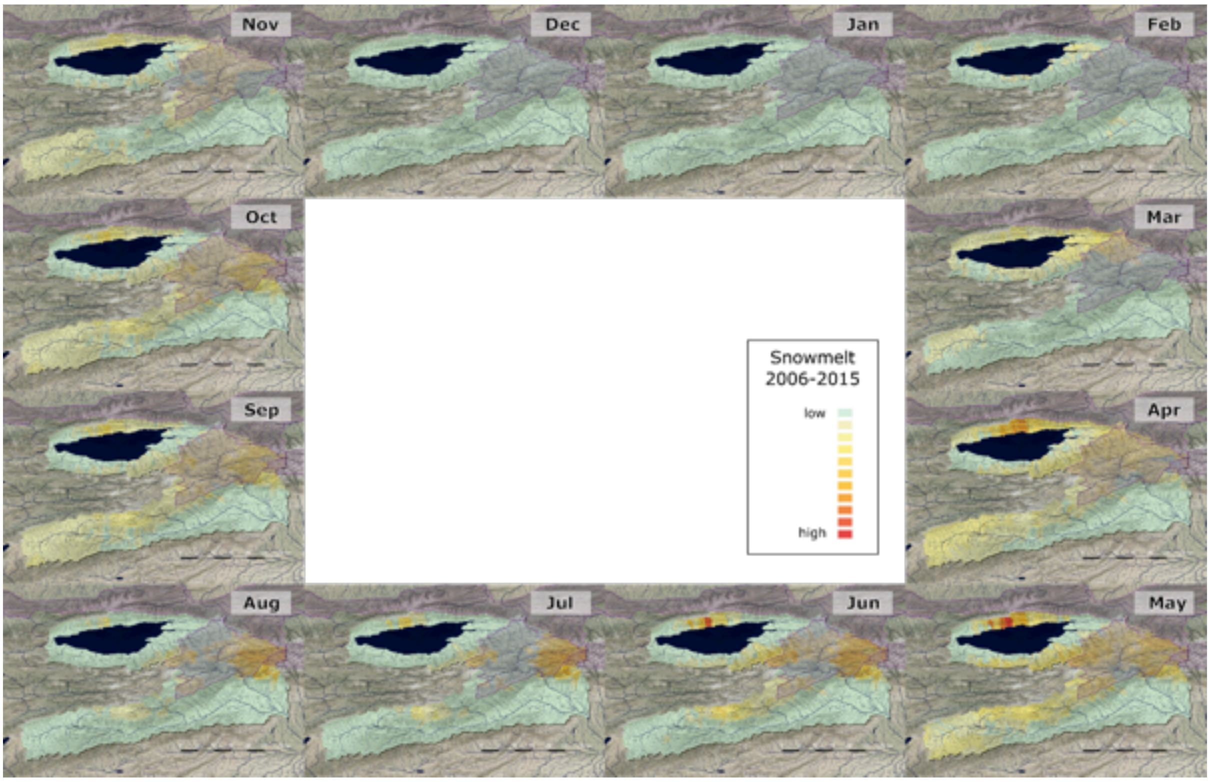
Methodology

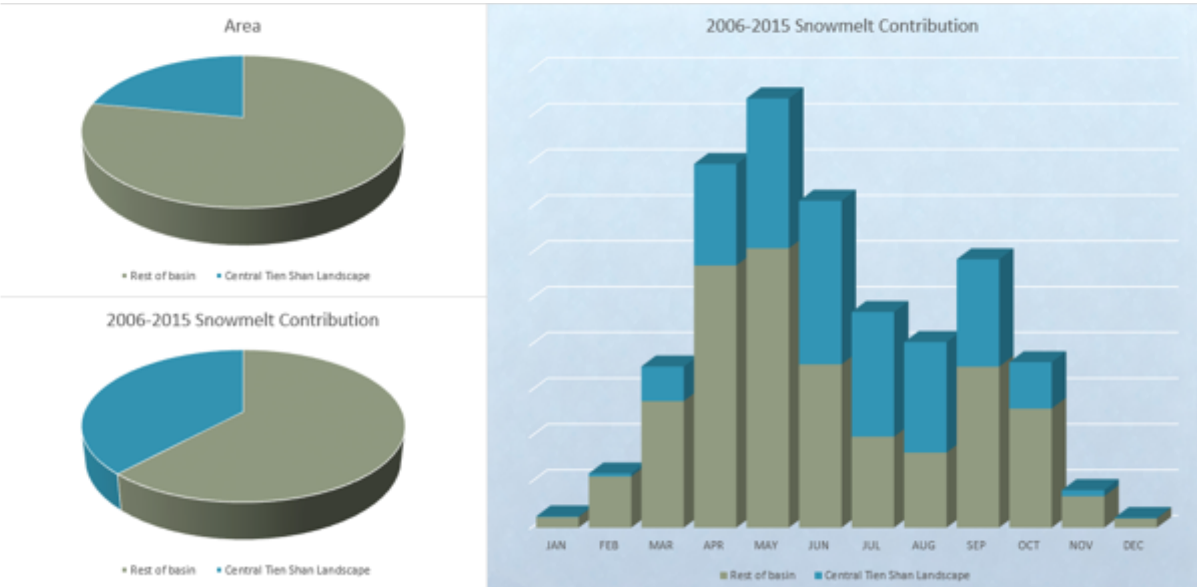
This is a map of MODIS/TERRA snow cover at 0.05 degree resolution with no additional processing required.

Data

MODIS/TERRA Montly Snowcover L3 at 5km (0.05 degree) resolution; Hall, Dorothy K., George A. Riggs, and Vincent V. Salomonson. 2006, updated monthly. *MODIS/Terra Snow Cover Monthly L3 Global 0.05Deg CMG V005*, [Year 2015, downloaded April 2016]. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Water provision functions; snow melt (2006-2015)





Analysis

Subbasin context

Since the snowmelt data comes from a different model (GLDAS-NOAH) than the water towers and aridity calculations (WorldClim); these cannot be linked into a single model.

Snow and glacial melt is the major water source for rivers in this subbasin. There are two peaks in the snowmelt graph,

- the first peak in snowmelt (in May) seems to depict the largest area where snowmelt, that has accumulated during winter melts off.
- the second snowmelt peak (in September) seems to peak due to early snowfall; precipitation that falls as snow at the end of the wet season, but still melts off because temperatures still reach above zero.

Under temperature rise due to climate change, the May peak in snowfall might melt off earlier; which will have direct results on the spring flows, as peak flows will shift accordingly. Under temperature rise, the September peak in snowmelt might increase in amount and more snow might melt off in October; this will have direct impact on the flows of the rivers. Both the May and September shift would be interrelated; if less snow falls in September/October, less snow will melt off in May

In both cases, it is of importance where the historic freeze line is located, what the temperature slope is, and, how precipitation patterns might change. In general, the temperature slope is flatter in landscapes with lower elevations (or with lower elevation differences) and steeper at higher elevations; this means that a temperature shift at lower elevations has a bigger spatial footprint than a shift at higher elevations.

Just north of Issyk Kul lake, there are a few rivers that also show a very high snowmelt signal; on the edge of Issyk Kul subbasin there are snowcapped mountains with glaciers that are connected to lake Issyk Kul. Baetov (2006) reports that already glacial melt has increased due to temperature rise, yet over the decades the water level of Issyk-Kul has decreased by about 2.5 meter; this decrease is attributed to over-allocation of water to irrigation systems.

Landscape context

The landscape provides a disproportionate amount of snowmelt to the subbasin, especially in the summer months, when water is in highest demand in the downstream (for irrigation purposes). The landscape therefore provides water provision to downstream locations, more than other locations in the subbasin. But, since peak snowmelt occurs in coincidence with freeze line dynamics, in a changing climate, under temperature rise, the timing and amounts of this water provision will decrease in reliability, which might become a challenge to downstream water resources planning.

Methodology

NOAH-GLDAS monthly data 2006-2015 is downloaded, it contains 28 bands of data; snowmelt is band 11 in this dataset. For every month, the 2006-2015 mean snowmelt component is calculated in a GIS, through adding all individual months.

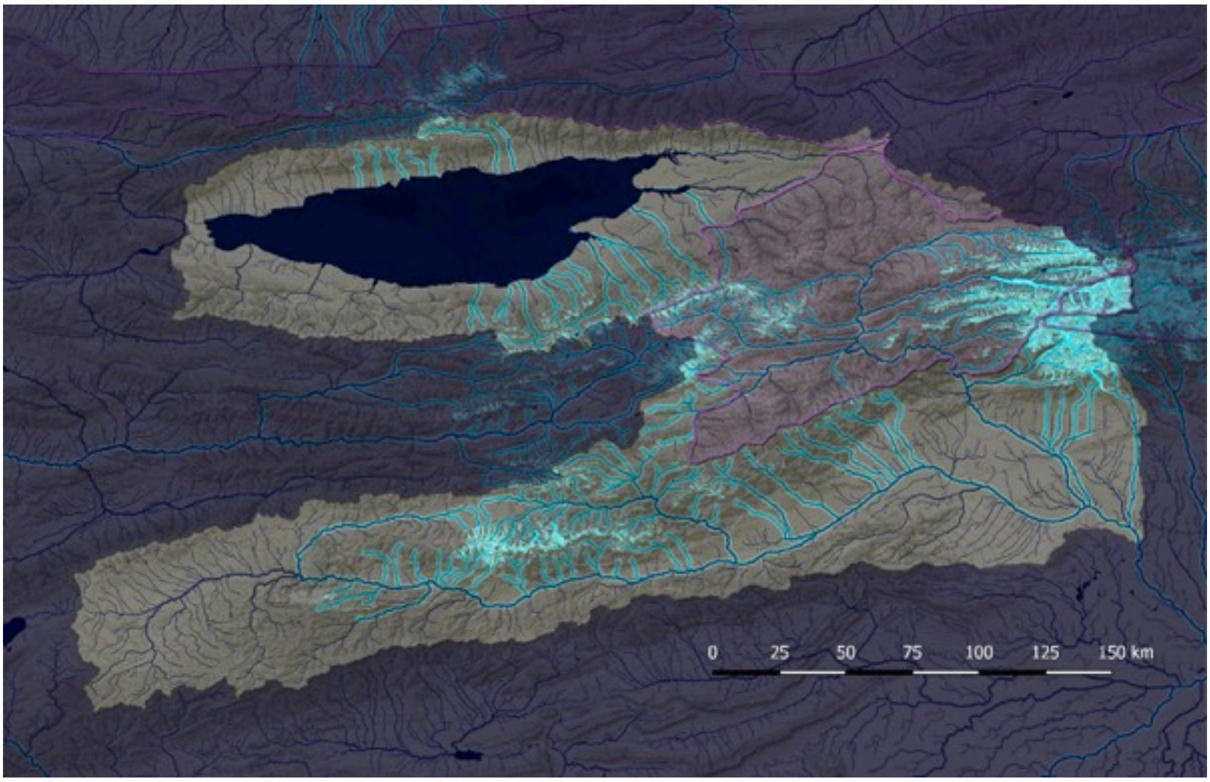
The mean snowmelt is then summarized in a GIS for each month by the selected HydroBASIN level 12 watersheds, and multiplied by each watershed area (in order to calculate quantities), both for the entire basin and the snow leopard landscape.

Data

NOAH-GLDAS V2.0, Monthly data on snowmelt from 2006-2015 at 0.25 degrees resolution
http://disc.sci.gsfc.nasa.gov/datareleases/gldas-version-2.0-data-sets

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Water provision functions; glaciers and glacial streams



Analysis

Subbasin context

Glaciers are important water sources because they can provide water to downstream throughout the year. Through regelation –pressure built up under thick layers of ice cause melting of the ice under the glacier- water keeps flowing from glaciers, regardless of the season. Therefore streams with glaciers in the headwaters do have different runoff pattern –as well as water chemistry- than streams with only seasonal snowmelt in the headwaters.

Glaciers can continue to exist due to the imbalance between snowfall and snowmelt; where there is more snowfall than snowmelt, snow accumulates over the years and the layers get pressed into ice. This is a process that takes hundreds of years; that is how long it could take from initial snowfall to melt-off at the foot of a glacier. Ice melts off under high pressure under each glaciers, which makes glaciers slowly slide down, until it reaches elevations with seasonal thaw that melts-off the foot of the glacier. Under rising temperatures, this elevation gets higher and higher up the mountain, which could then escalate glacial melt off. In some cases, glaciers have pushed debris down the mountain, and under escalated melt-off, melt water is building up behind these walls of debris, creating risks for glacial lake outburst floods (GLOFS).

According to the glacier database (GLIMS, 2016) the larger subbasin contains glaciers inside and at its boundaries, with the highest glacial coverage on the eastern side of the basin. From the rivers that feed into lake Issyk Kul, only some at the north and at the southeast of the lake have glaciers in the headwaters. The largest/longest stream, coming in at the very east of the lake does not drain any glacier, its main water source would therefore be the seasonal snowmelt.

Though the map shows the spatial extent of the glaciers, it does not show the total volume of ice/water in each glacier. Each glacier has its own particularities that explains its existence, how it accumulates snow, and releases its water. To get a full understanding about the functioning of glacial water release would require detailed insights at the glacier level.

Landscape context

An –estimated- sixth of the landscape's area is covered under glaciers. Apart from the mountaintops at the very east -considering the historic freeze line- all of its glaciers are exposed to three months of thaw (July-September). This implies that snowfall in winter is such that they blanket the glaciers over summer while the snow melts off; otherwise the glaciers would not exist and would historically have melted off. This is a precarious balance, and under rising temperatures (and/or changed snowfall patterns), it has been observed that glaciers are shrinking (Baetov, 2006).

Methodology

This is a map of the GLIMS database.

The glacial streams were created with HydroSHEDS 15s drainage directions. For that, the GLIMS polygons were converted to a 15s grid, and ran through a flow accumulation. A stream network was defined using HydroSHEDS 15s drainage direction, with the glacial flow accumulation attributed.

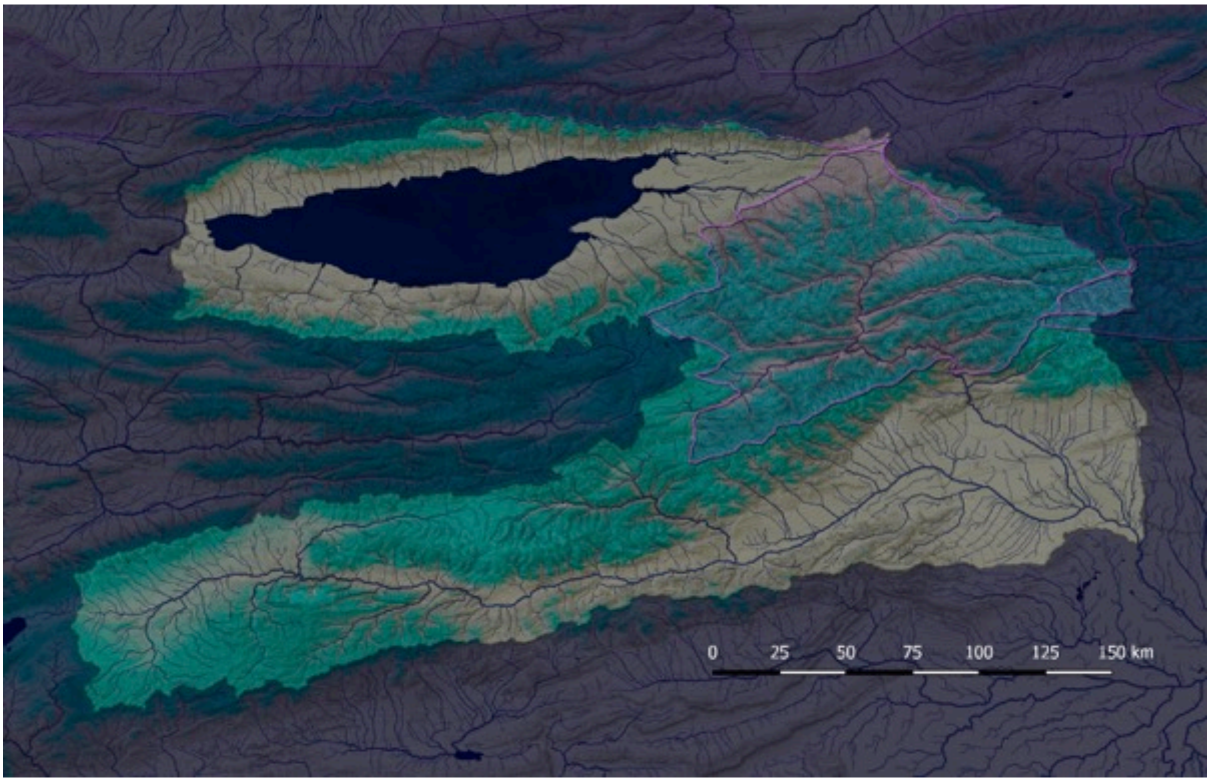
Data

GLIMS glacier database; GLIMS, and National Snow and Ice Data Center. 2005, updated 2012. GLIMS Glacier Database, Version 1. [polygons]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: http://dx.doi.org/10.7265/N5V98602. [April 2016].

HydroSHEDS 15s drainage directions; Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. Data is available at www.hydrosheds.org

Baetov, R. *Lake Issyk-Kul. Managing Lakes and their Basins for Sustainable Future;* International Lake Environment Committee Foundation: Kusatsu, Japan, 2006; pp. 193–204.

Water provision functions; permafrosts



Analysis

Subbasin context

The permafrost database is the work of Gruber (2012). It is a function of air temperature, ruggedness, and permafrost extents from earlier global assessments. The study acknowledges that the permafrost extents are mapped for consistent reference, but due to the lack of consistent information on permafrost, it is does not provide a reliable groundtruth (Gruber, 2012).

Overall, it provides a consistent and best-informed overview where permafrosts are located in the wider subbasin: i.e. on high elevations but not in the river valleys. So there is a component of being in the upstream source areas.

Though this map provides essential insight on the extent of permafrost, actually there are a wide range of permafrosts all with their specific seasonal impact on the landscapes in which they occur. The characteristic of each permafrost is essential to know in order to understand its role in landscape hydrology, or its vulnerability to climate change. At the moment, the map therefore illustrates the matter of uncertainty where permafrosts do occur; it depicts where changes are likely to happen under changing climate, but does not indicate how the landscape will change.

Possible changes already observed to coincide with permafrost degradation can be, but are not limited to:

- increased landslides, due to loss of permafrost slopes will lose their stability,
- decreased seasonal levels of groundwater, if permafrost dissolve or sink deeper, the active layer also sinks deeper, possible causing the disappearance of seasonal wetlands in alpine meadows, but also changes (or degradation) of surface vegetation,
- changed runoff patterns as sub-surface hydrology changes,
- release of greenhouse gasses that have been stored in permafrosts, and changes in runoff water chemistry.

These changes will become more dramatic at the frontier between permafrost and none-permafrost lands. This frontier runs throughout all the headwaters of this subbasin, and any climate change impacts on permafrosts will likely trigger unprecedented change at the subbasin level.

Landscape context

The permafrosts here are located at the highest elevations on the mountain slopes, covering an estimated 80 % of the landscape. The northern slopes of the landscapes, draining towards lake Issyk Kul, are without permafrost, as well as the river valleys in the southern parts of the landscape.

As inside the landscape, the permafrosts are mainly located on the mountain slopes, under increased temperatures the spatial footprint of any change will be minimal, yet small changes to slope stability will have dramatic local impacts.

Through visual observation it can be deducted that the ratio between circumference and surface of permafrost cover is very high inside the landscape. This implies that any shift in permafrost frontier will have significant impact on the landscape and its downstream.

Methodology

This is a map of the PZI database. From the website:

"The Permafrost Zonation Index (PZI) or a corresponding map color indicates, to what degree permafrost exists only in the most favorable conditions … or nearly everywhere ... These local conditions affecting permafrost occurrence will partly exhibit regional trends (e.g. mean snow cover characteristics or continentality), partly vary over typical distances on the order of several km (e.g. shaded or sun-exposed side of a mountain), and partly over tens to hundreds of meters (e.g. snow drift, vegetation, ground material). These conditions need to be assessed during interpretation, depending on the intended purpose of using the PZI map. This product is likely to be most valuable in remote regions where only sparse reliable information exists.The accompanying publication points to the importance of heterogeneity and uncertainty in the derivation and use of such permafrost zonation maps."

And from the paper (Gruber, 2012);

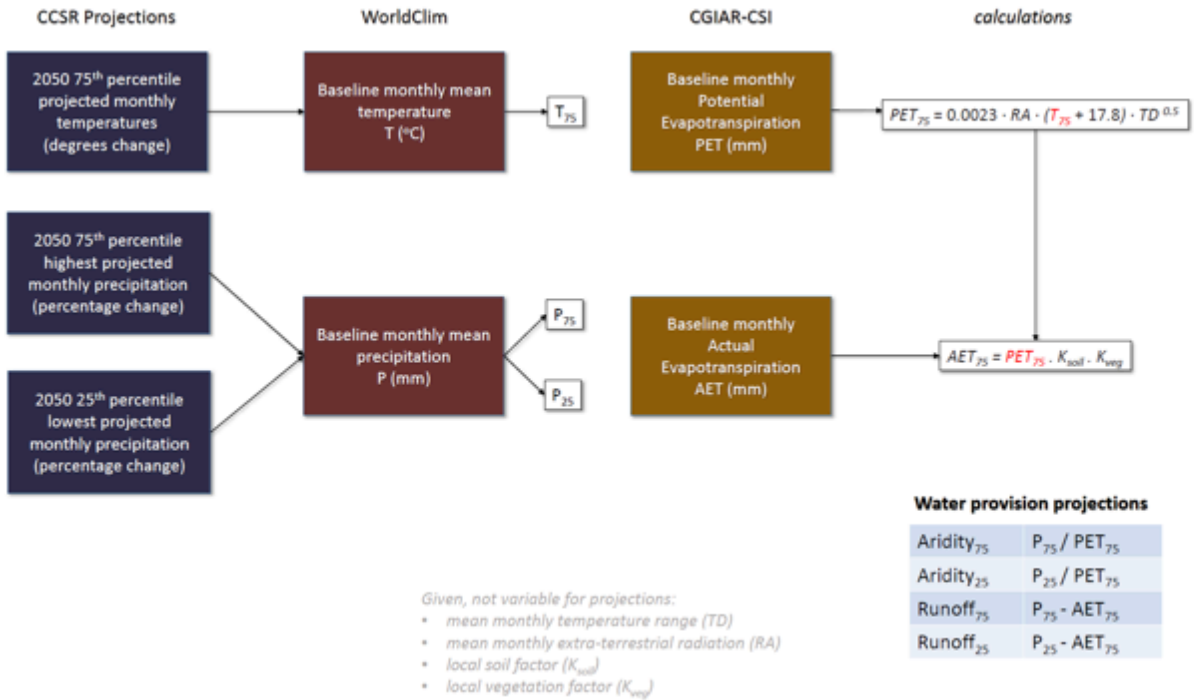
"*Established relationships between air temperature and the occurrence of permafrost are re-formulated into a model that is parametrized using published estimates. It is run with a high-resolution (<1 km) global elevation data and air temperatures based on the NCAR-NCEP reanalysis and CRU TS 2.0. The resulting data provide more spatial detail and a consistent extrapolation to remote regions, while aggregated values resemble previous studies. The estimated uncertainties affect regional patterns and aggregate number, and provide interesting insight. The permafrost area, i.e. the actual surface area underlain by permafrost, north of 60S is estimated to be 13–18□106 km^2 or 9–14% of the exposed land surface. The global permafrost area including Antarctic and sub-sea permafrost is estimated to be 16–21 x 10^6 km^2. The global permafrost region, i.e. the exposed land surface below which some permafrost can be expected, is estimated to be 22±3 x 10^6 km^2. A large proportion of this exhibits considerable topography and spatially-discontinuous permafrost, underscoring the importance of attention to scaling issues and heterogeneity in large-area models."*

Data

Global permafrost database, Permafrost Zonation Index (PZI); Gruber, S.: *Derivation and analysis of a high-resolution estimate of global permafrost zonation*, The Cryosphere, 6, 221-233, doi:10.5194/tc-6-221-2012, 2012. http://www.geo.uzh.ch/microsite/cryodata/pf_global/

Central Tien Shan Climate Projections

This section discusses how sensitive the different water provision functions are to different projections of climate change. It makes use of the same datasets as were being used for the water provision functions and applies the projections produced by the Center for Climate Systems Research, under the ADVANCE partnership with the WWF (CCSR, 2016)

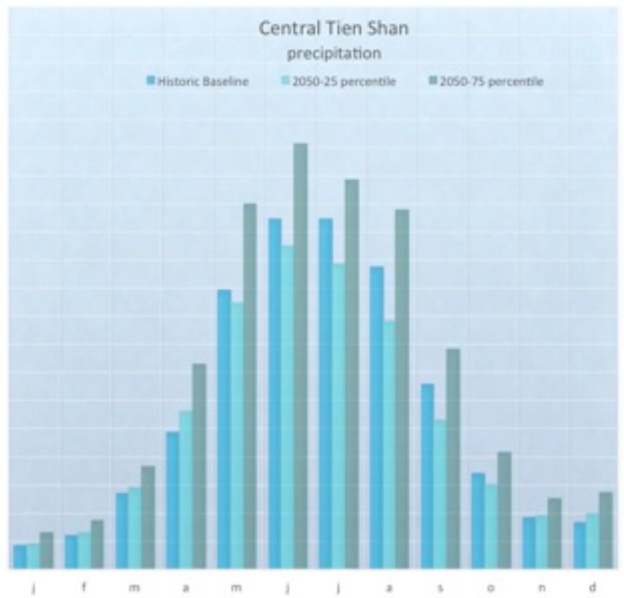


- CSSR Projections are calculated at 0.25 degree resolution; WorldClim and CGIAR-CSI datasets are at 1km^2 resolution
- Calculations are upscaled/downscaled to HydroSHEDS level 12 (~100 km^2) watersheds, both for the snowleopard landscape and their larger subbasins
- The results are presented as graphs, this is in order to communicate *relative* changes to seasonality and to identify uncertainties in the projections; hence the water balances are not presented in millimetres of change
- In the annex, one quantitative example is given of a single (watershed) entry, representative for the snow leopard landscape; this quantitative example provides an insight in why certain graphs show the variability and uncertainty.

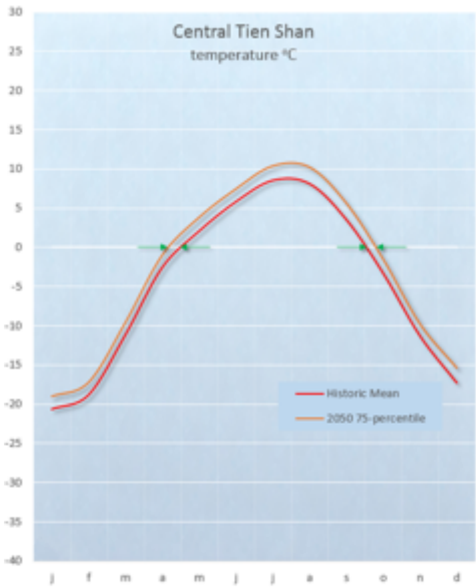
These projections are based on bias-corrected output from 21 General Circulation Models run under 2 scenarios of future emissions (moderate-emissions RCP 4.5 and high-emissions RCP 8.5), for a total of 42 projections. Projections for 2050 reflect average climate over 2041-2070. A most likely range of future climate change is defined from the 25th to the 75th percentiles of the suite of projections for precipitation. For temperature, a single higher-end estimate (75th percentile) is used for simplicity. While changes within this range are most likely, changes outside the range are also possible based on the full suite of projections.

•

Precipitation and temperature projections



Historic precipitation compared to the low end of the range of climate projections (25th percentile) and the high end of the range of climate projections (75th percentile) in the 2050s, horizontal axis crosses at 0 mm.



Historic temperature compared to the maximum projection (75th percentile) of 2050 (reference to CCSR-report, 2016). Arrows denote projected future loss of frost season duration. Note that this figure only depicts the higher end of the most likely range of future temperatures

Observations:

- From November to April, both the high and the low ends of the most likely range of projected changes show an increase in precipitation compared to the baseline
- In the high-end-projection, there will be annually about 25% extra precipitation, in the low end projection there will be around 5% less precipitation annually
- The largest difference in amounts of precipitation between high- and low end projection occurs in May and June, and the low-projection is about 25% lower than the high-projection; this is a measure of uncertainty in the projections
- Due to increased temperatures, there is an approximate one month decrease in freeze/winter season; about 2.5 weeks in April, and about 1.5 weeks in October, indicated by the green arrows in the temperature chart

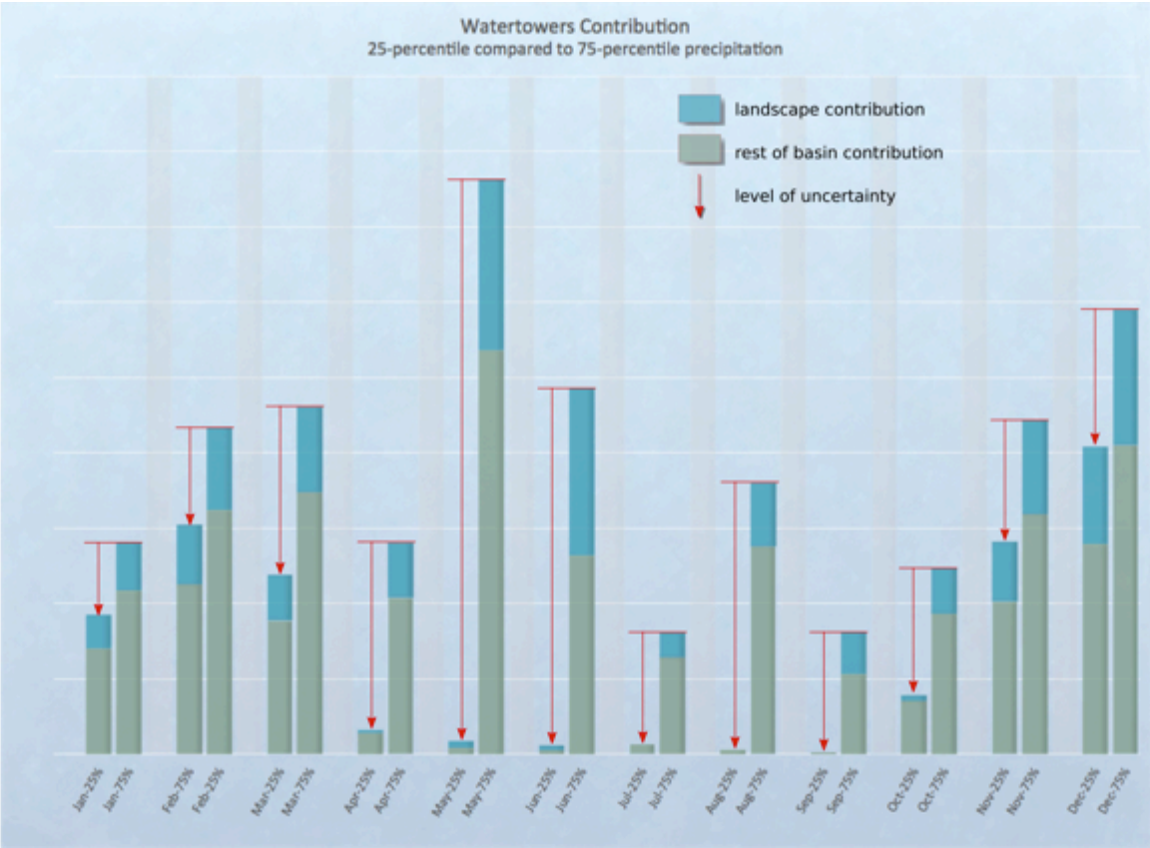
Data

Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Climate Projections on future temperatures and precipitation by Center for Climate Systems Research, Earth Institute, Columbia University, under the ADVANCE partnership, 2016.

Watertower projections



This graph shows how much water will locally runoff based on two 2050 scenarios, one with the low 25 percentile precipitation and one with the high 75 percentile precipitation. Red arrows show the range of changes in runoff based on the range of climate changes, and therefore illustrate uncertainty in future climate impacts on runoff. The figure compares the overall sub-basin runoff (green colors under at the bottom of the bar chart) to the runoff specific to the snow leopard landscape (blue colors at the top of the bar chart). The horizontal axis crosses at 0 mm. In the annex, a graph shows the same range of projections in compirison with the historic baseline.

During winter month, most of the contribution will fall as snow and will accummulate untill spring, when it melts off as snowmelt. In the spring and summer months, when downstream water demands are at its highest, the difference between the high and low ends of the range of projections show a very high difference, e.g. from almost zero to the highest annual value in May. This indicates a severe measure of uncertainty on what might actually happen to local runoff under climate change in the spring/summer months.

This graph would help to identify if the role of the snow leopard landscape in water provision would change under the climate projections.

There is a proportionality in changes to the landscape versus the rest of the subbasin; if the subbasin gets drier, so would the landscape; if the subbasin would get wetter, so would he landscape. So it is not expected that the relative role of the landscape in water provision would change much.

Though from July to September, the role of the landscape in water provision might increase somewhat –under the high-precipitation projection. Yet the uncertainty here is much higher as well, so it is very difficult to assess what might happen; this would require more specific insights.

Data

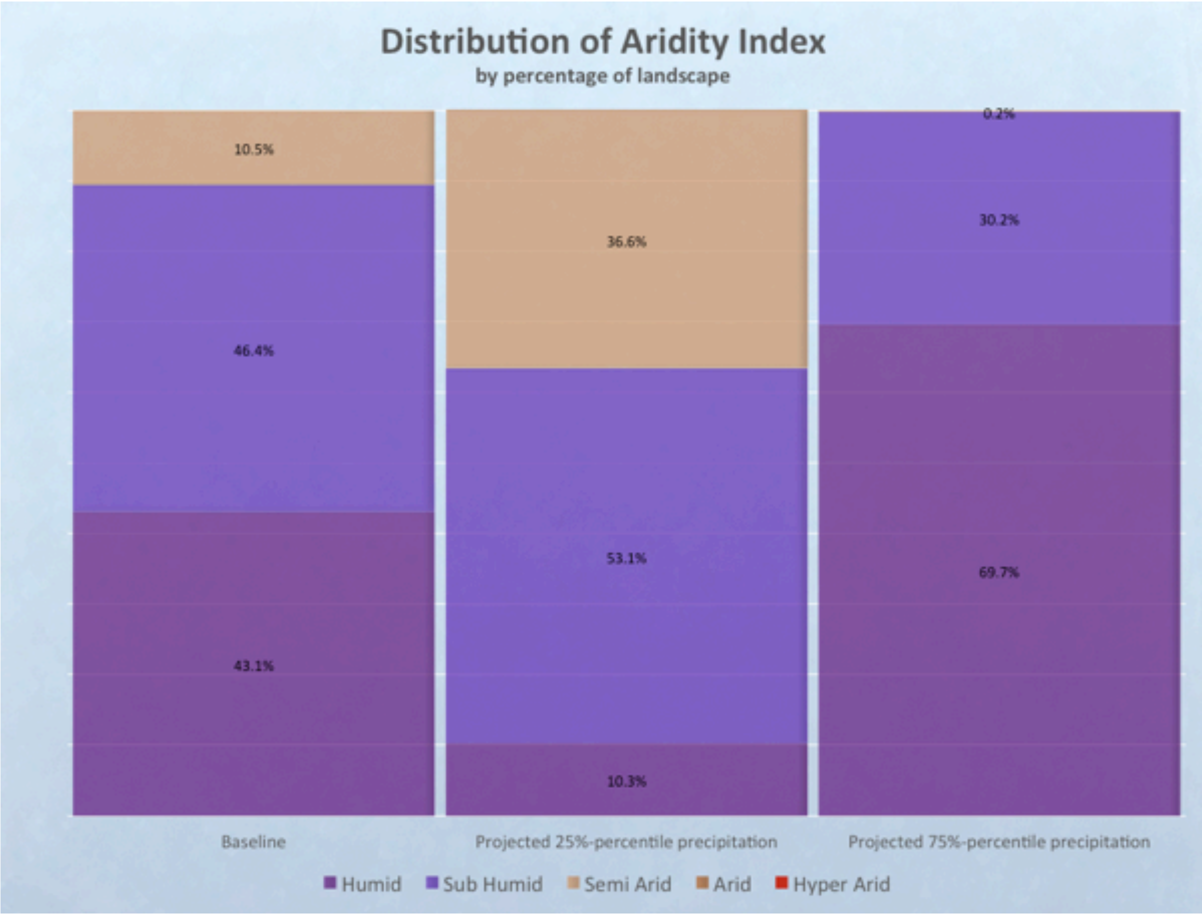
Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Trabucco, A., and Zomer, R.J. 2010. Global Soil Water Balance Geospatial Database. CGIAR Consortium for Spatial Information. Published online, available from the CGIAR-CSI GeoPortal at: http://www.cgiar-csi.org

HydroBASINS, level 12, ~100 km^2 watershed outlines; Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org

Climate Projections on future temperatures and precipitation by Center for Climate Systems Research, Earth Institute, Columbia University, under the ADVANCE partnership, 2016

Projected change in aridity index inside the landscape (annual)



These graphs compare the current (baseline) situation of aridity versus humidity to the high and low ends of the range of projected climate change defined from the 25th percentile of projected change in precipitation for 2050 (in this case, drier) to the 75th percentile projected of change in precipitation for 2050 (in this case, wetter) among 42 climate model runs. The range between the low and high estimates represents the most likely range future changes , and herefore illustrates a measure of uncertainty.

The classification of aridity versus humidity is a measure to which extent the precipitation is a limiting factor in vegetation growth; more arid landscape will have more drought resistant vegetation. The aridity puts this in perpective of other climatic parameters, such as temperature or solar radiation. Initially, this graph was calculated on a monthly time-scale (see annex), but for the winter months this reulted in relative high humidities; which worked counter-intuitive. In essence, the monthly graphs show that in winter precipitation is not the limiting factor; but low temperatures are.

In the annual balance, the seasonality is balanced-out. Under the low-precipitation projection, the semi-arid extent would more than triple at the expense of humid areas; humid areas will shift to sub-humid, and sub-humid to semi-arid. Under the high-precipitation projection, the semi-arid areas will disappear and turn more towards sub-humid, and even humid.

The difference between to low and high ends of the most likely range of future precipitation is significant; again, this indicates a high level of uncertainty on what the future distribution of aridity and humidity will be for the Central Tien Shan landscape.

Data

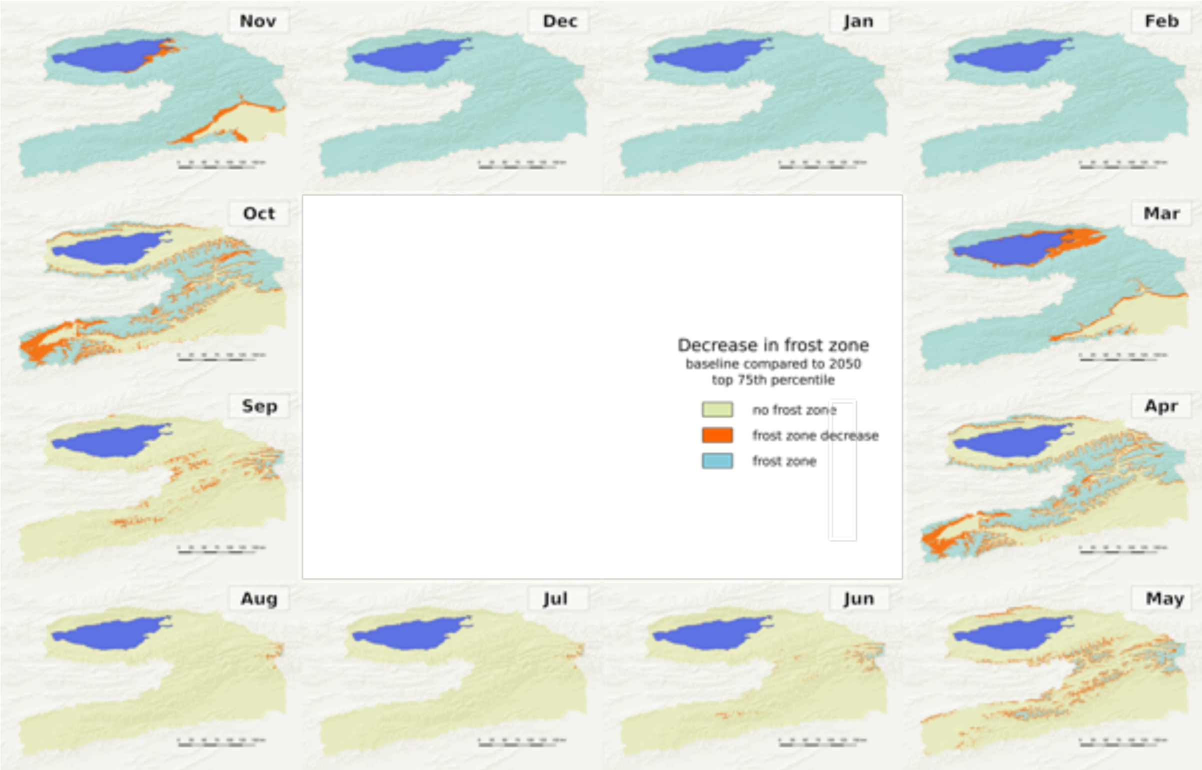
Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

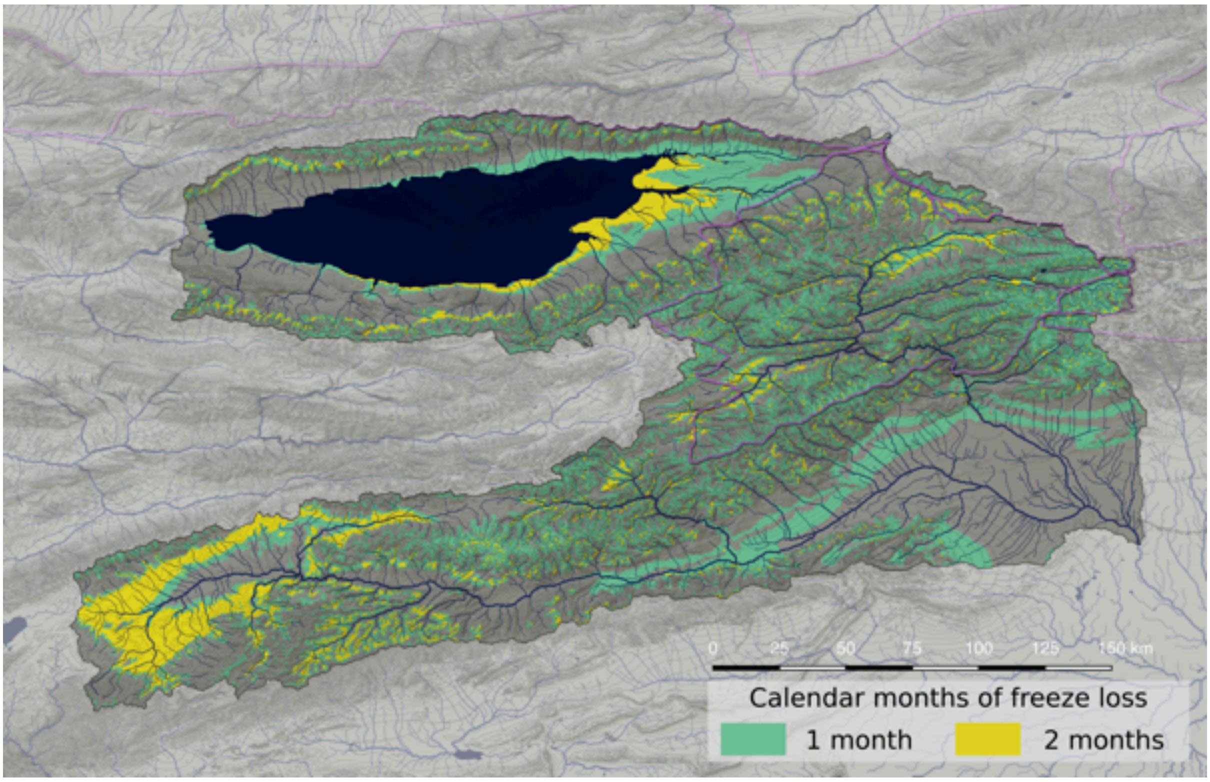
Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution; Zomer RJ, Trabucco A, Bossio DA, van Straaten O, Verchot LV, 2008. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. Agric. Ecosystems and Envir. 126: 67-80.

Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

Climate Projections on future temperatures and precipitation by Center for Climate Systems Research, Earth Institute, Columbia University, under the ADVANCE partnership, 2016

Decrease in monthly freeze extent under temperature rise





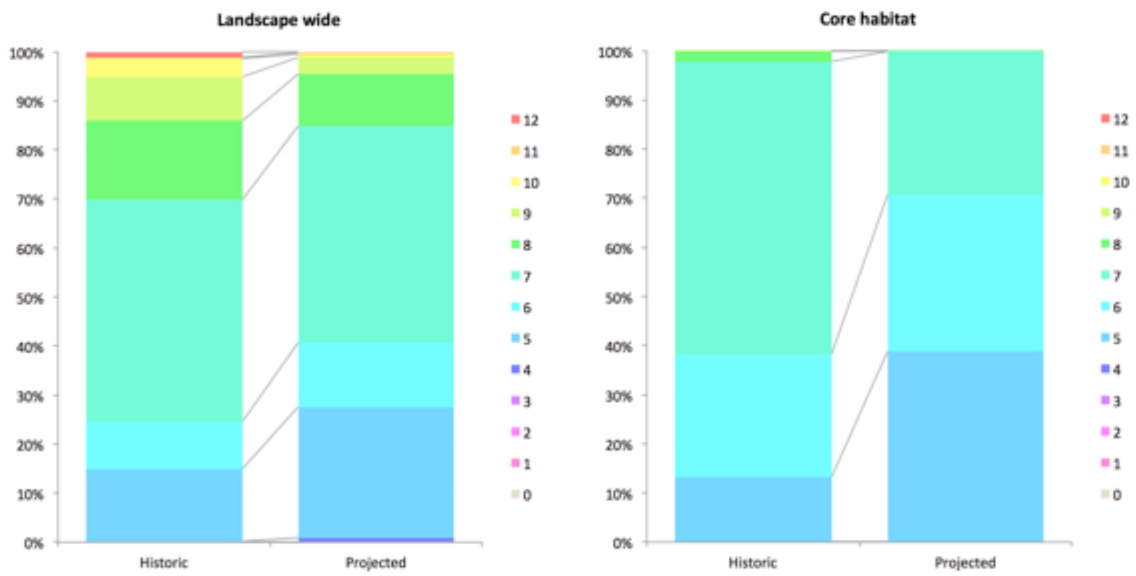
This mapset illustrates for each month what the spatial footprint would be on the freeze frontier under projected temperature rise. The baseline freeze extent guides a landscape's freeze and thaw cycles, and any change to this, will result in different patterns of snowfall and snowmelt, and other cryosphere interactions (e.g.glaciers, permafrost).

In order to visualize those interactions, the online version of this mapset would allow for each monthly map to be overlaid with the baseline snowfall, snowmelt, glacier and permafrost maps. In such a way it could be visualized how the timing and spatial footprint of the freeze/thaw cycle would change under projected temperature rise.

The area in the Southwest, the headwaters of the Aksay will see a large change in the months of April and October; this might directly impact snowfall in these months and generate more direct runoff in these months (and less snowmelt for other months)

In general, the decrease in freeze extent closely follows the baseline follows the freeze frontier, and changes are within the range of a few hundred meters to a few kilometres. Yet for mountaintop snow cover and glaciers, such an impact might be dramatic (May to September).

Overall duration – in months– of historic winter versus projected (Columbia-CCSR projection 2050 top percentile).



The main trends these graphs show that the core snowleopard habitat does hardly contain areas with more than 8 months of winter (while this covers ~30% of the landscape historically). No part of the landscape experiences less than 5 months of freeze, even under the temperature projection, this will not change.

Under projected change in temperature, the core habitat will overall experience decrease in winter duration, but will stay within the historic upper and lower limits. Where historically the majority of the snow leopard landscape would experience 7 months of winter (~60 %), in the projections this area would halve (~30 %). Under the projection, the area that experience 5 months of freeze (12 %) would increase to about ~40 % in the core habitat.

Yet, the main change here is not only the direct link to number of freeze months, but how this transition will impact the landscape; snowfall/melt, glacial melt, permafrost coverage and depths.

Data

Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

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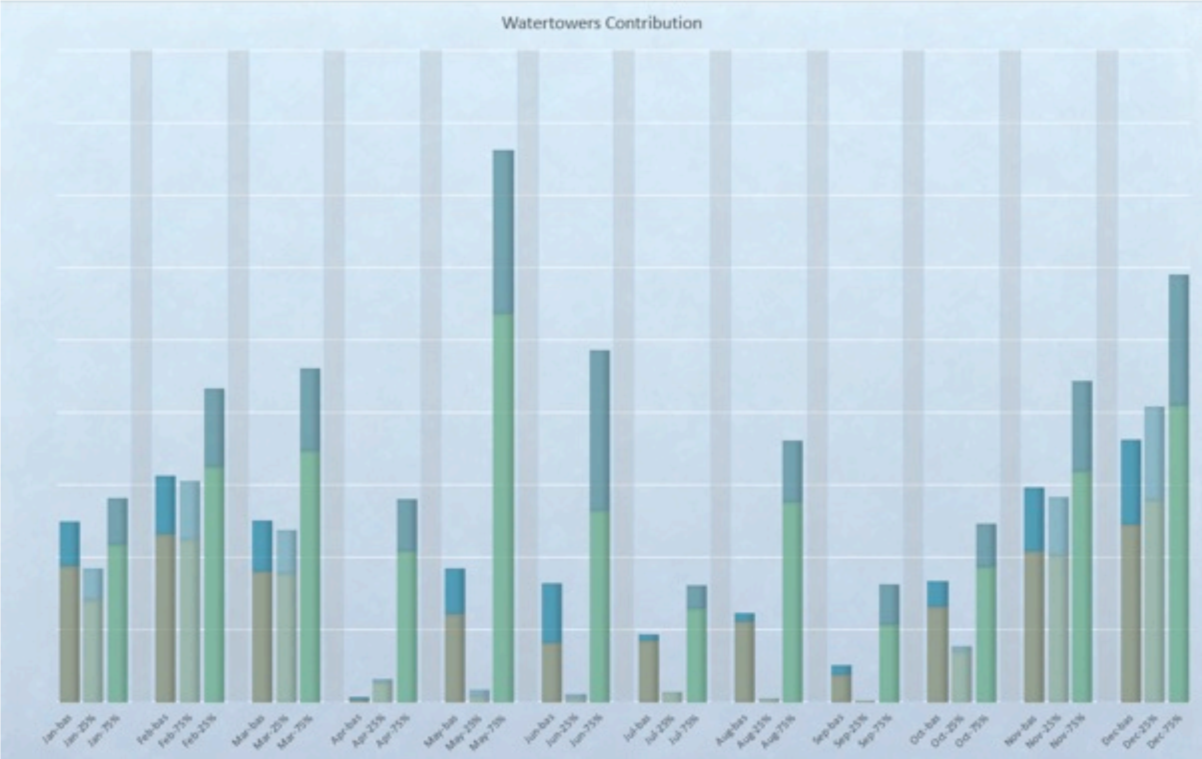
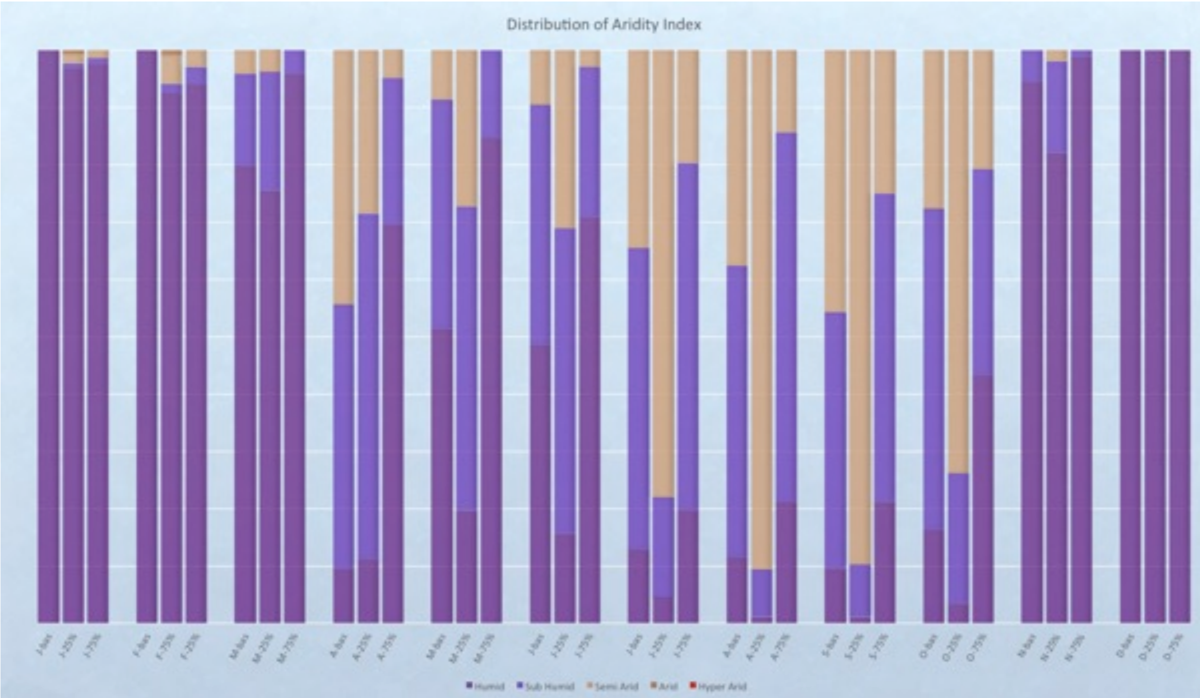
Annexes

Watertower contributions (baseline vs 25-percentile vs 75-percentile)



Projected change in aridity index inside the landscape (monthly)



The distribution of aridity index show to which extent the landscape is changing towards a drier or wetter landscape. In terms of water use, this would imply to which extent crops could depend on precipitation or require additional irrigation. In winter, humidity is always relatively high, because due to freezing temperatures, plants and soils do not require water for evapotranspiration; during this period, tempreatures (and not precipitation) are the limiting factor for potential evapotranspiration.

In general, under drier conditions the dry season will be more extreme, last longer in most locations, but also start later in spring (see April values).

Under the low-precipitation projection, the semi-arid extent would double at the expense of sub-humid and humid areas in the summer months (July-October). Though under the high-precipitation projection the semi-arid extent would slightly decrease for those months.

Though both projections are equally plausible in future, the monthly airidity index in the summer months is *more skewed towards increased aridity* under the low-precipitation projection (CL, 2016), whereas changes under the high-precipitation projection are not too dramatically different from the current situation.

Quantitative example

Basin ID: 22724	**area_km^2:**	108.2	**lat:**	42.625	**lon:**	78.875								
Central Tien Shan Landscape			**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**
baseline														
temperature	^{o}C		-17.02	-15.24	-7.45	1.15	5.92	9.71	12.25	11.69	7.06	0.17	-7.92	-13.79
precipitation	mm		6.98	9.10	18.03	31.35	54.00	63.27	61.93	54.01	36.19	23.06	13.72	11.02
AET	mm		0.83	1.84	13.61	35.00	51.27	60.95	65.11	54.68	33.92	17.14	5.38	1.42
PET	mm		2.04	4.13	24.17	60.66	91.44	112.34	126.80	113.02	73.24	37.80	12.67	4.04
runoff	mm x km^2		665.56	785.71	478.09	0.00	295.66	250.37	0.00	0.00	245.34	641.02	902.72	1037.97
2050_25 percentile														
precipitation change	%		109.79	106.27	109.08	116.07	95.23	91.31	88.61	83.15	79.34	88.72	103.08	125.10
precipitation$_{25}$	mm		7.67	9.67	19.67	36.39	51.43	57.77	54.88	44.91	28.72	20.46	14.14	13.78
runoff$_{25\ (T75)}$	mm		555.89	721.26	427.22	0.00	0.00	0.00	0.00	0.00	0.00	178.80	854.07	1265.79
2050_75 percentile														
temperature change	^{o}C		1.59	1.63	1.60	1.51	1.73	1.55	1.81	1.98	2.03	1.75	1.60	1.86
temperature$_{75}$	^{o}C		-15.43	-13.61	-5.85	2.66	7.65	11.26	14.06	13.67	9.09	1.92	-6.31	-11.94
precipitation change	%		153.38	147.81	133.38	148.34	126.06	119.92	110.75	121.26	114.88	115.71	130.31	157.66
precipitation$_{75}$	mm		10.71	13.45	24.05	46.50	68.07	75.87	68.59	65.49	41.58	26.69	17.88	17.37
AET$_{75}$	mm		2.53	3.00	15.72	37.78	55.00	64.39	69.03	58.34	36.69	18.81	6.25	2.08
PET$_{75}$	mm		6.21	6.75	27.91	65.47	98.09	118.69	134.44	120.60	79.22	41.49	14.72	5.91
runoff$_{75}$	mm x km^2		885.26	1130.19	901.27	943.85	1414.85	1241.53	0.00	773.57	528.27	852.40	1258.27	1653.99

These numbers are presented as reference to the different graphs; they will explain why certain values occur

Under the baseline April, it shows that local runoff is zero because baseline AET surpasses baseline precipitation; spring vegetation (and soils) start greening and have a high water demand

Overall, the local runoff (precipitation minus AET) has relatively low values in this context; small changes to precipitation or AET might therefore lead to larger changes over the water balance; this is what is occurring in May; under low-precipitation projections, the landscape will not generate any runoff, under high precipitation projections the month becomes the second wettest of the year, and quadruples over baseline values.