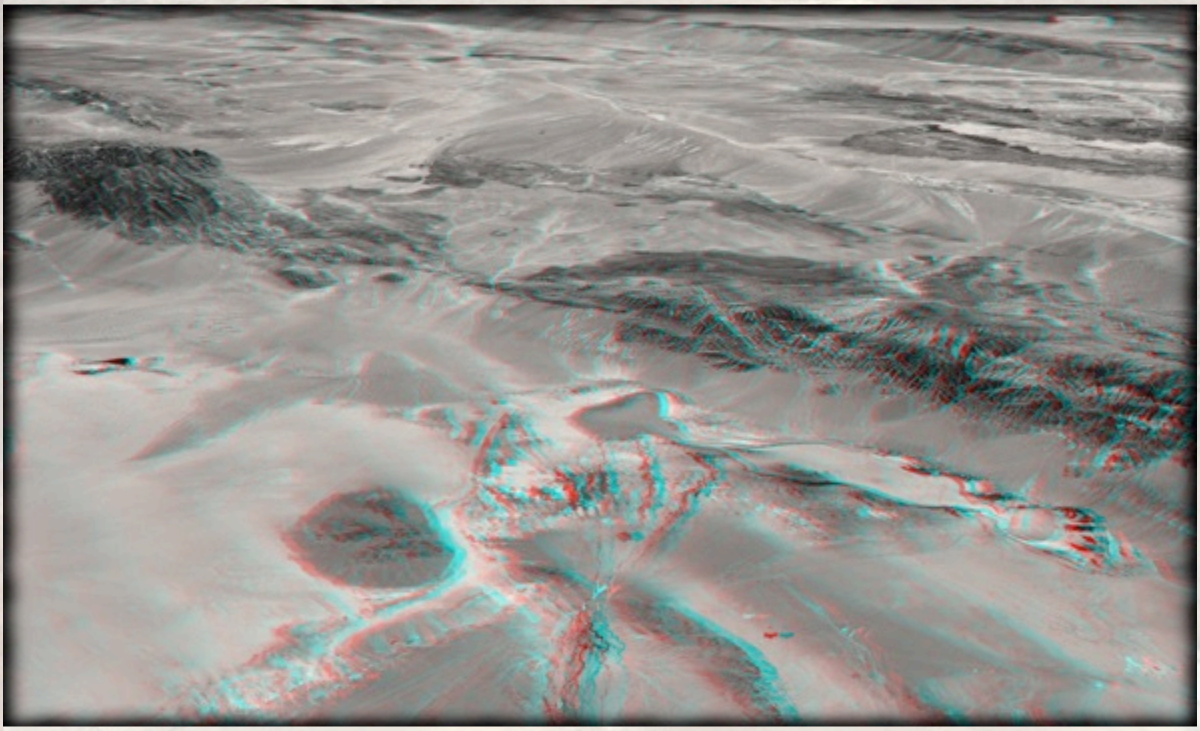
South Gobi Landscape

Water Resources

and

Climate Change Sensitivity

Analysis



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

By Nikolai Sindorf

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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

Nikolai Sindorf
about.me/niksin
niksin@gmail.com
Vientiane, Laos, +7 GMT

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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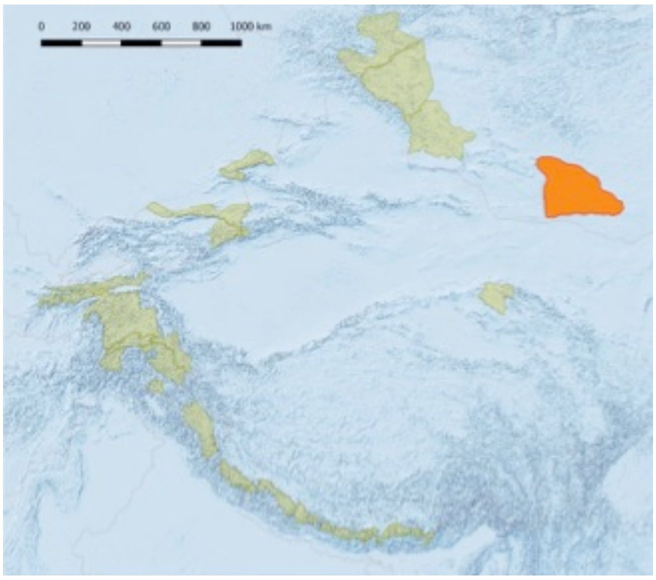
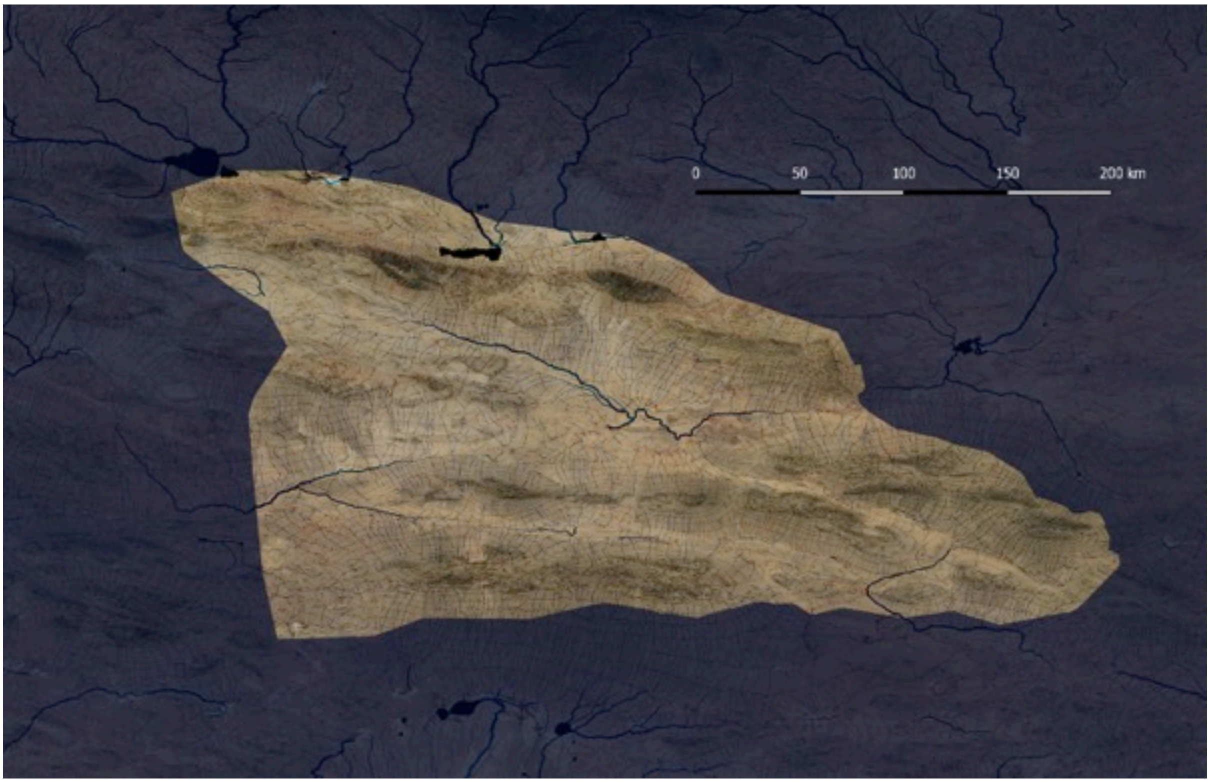
South Gobi Landscape

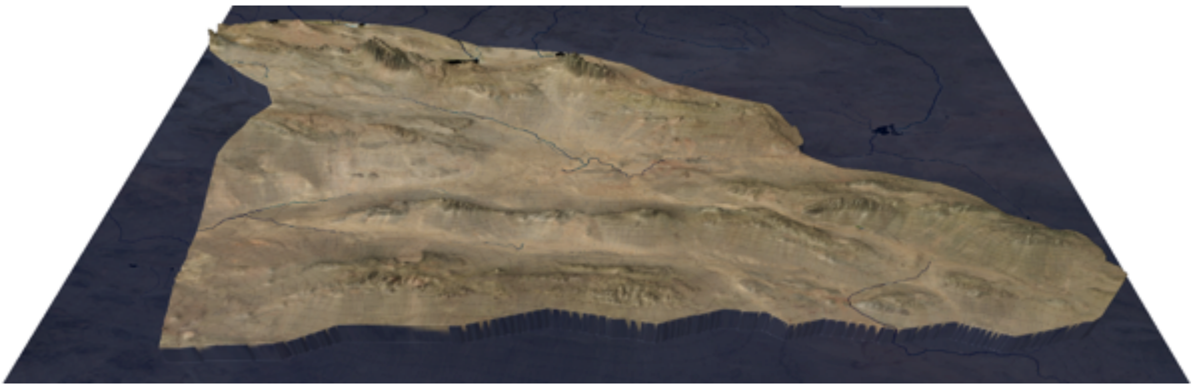
Country: Mongolia
Size: ~82,000 km^2
Population:
Highest elevation: ~4,000 MSL
Lowest elevation: ~700 MSL

Connections:
none

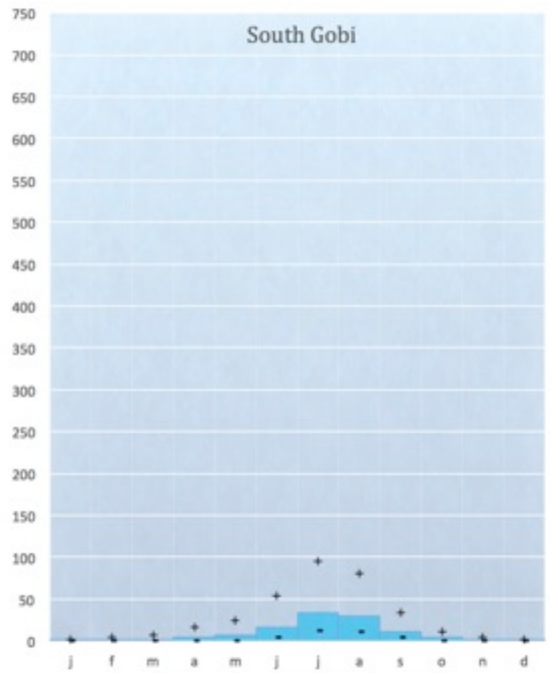


Overview maps

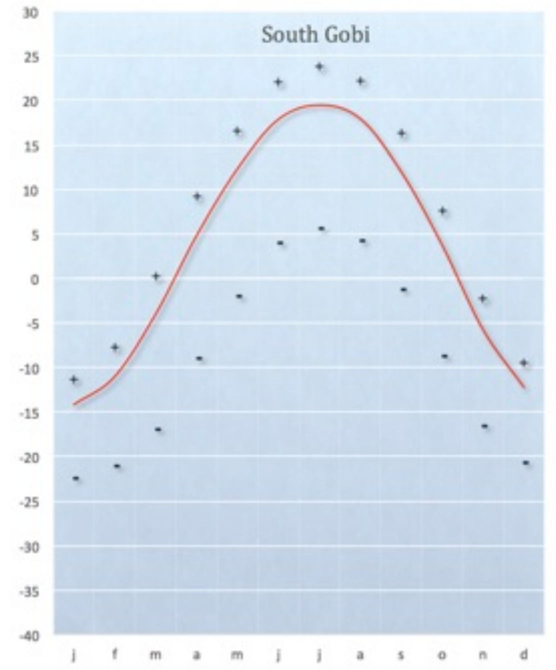




Basic climate



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

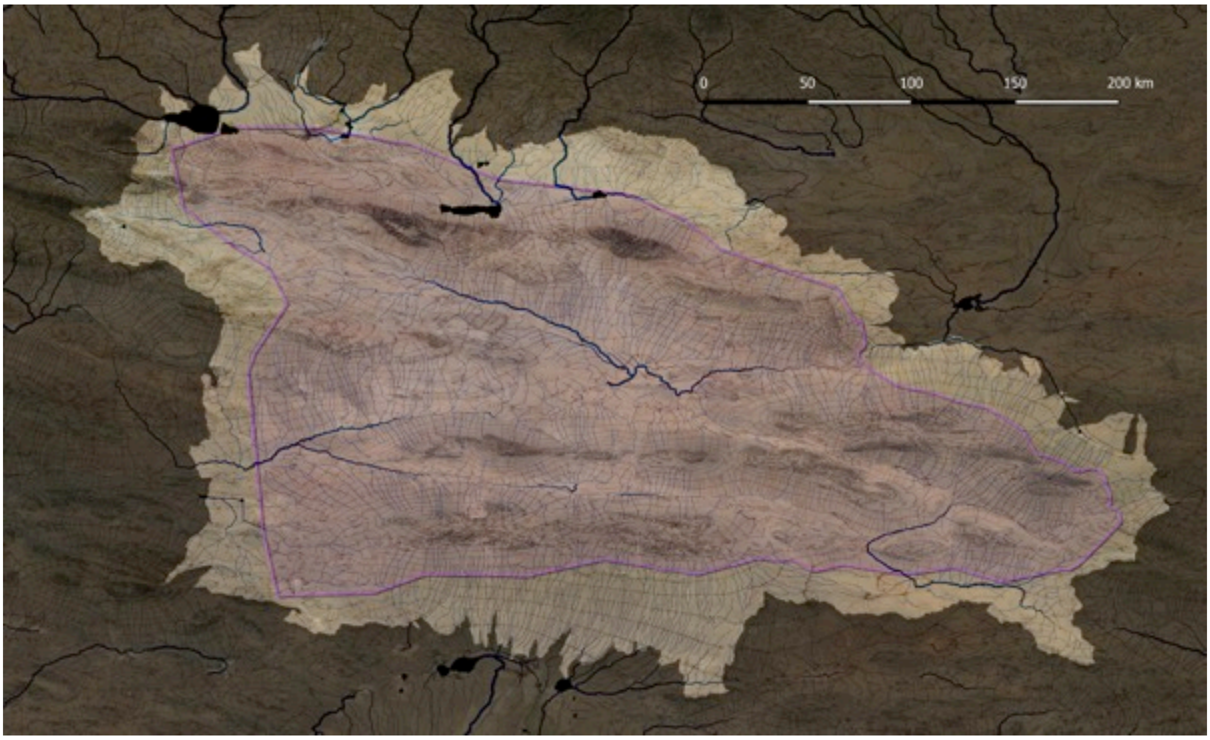


Historic monthly mean temperature
in centigrades (WorldClim, 1950-2000)
+ = highest mean of the landscape
- = lowest mean of the landscape

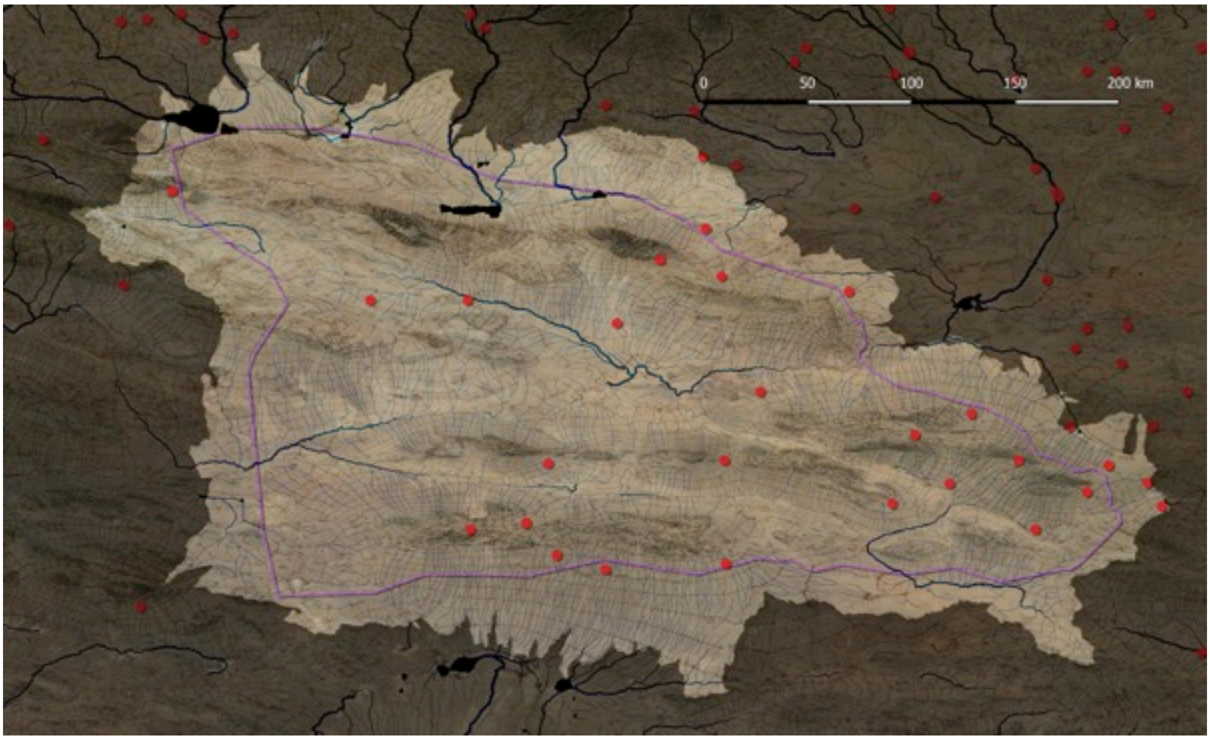
The precipitation distribution illustrates that the South Gobi landscape is a very dry area, where some minimal precipitation occurs around the summer months (June-September). Since this is a mean value, and since the landscape is a desert-like climate, it is very likely that the precipitation falls in some years, but not all years; showing high variability

The mean temperature curve shows very steep spring and fall directions. Winter lasts from November till March. The mean temperature is very close to the maximum-landscape temperature; this is because the landscape is for the largest part a great plain, with a few mountain ranges which show up as the minimum temperature, but these do not influence the overall mean temperature too much.

Subbasin context; hydrography

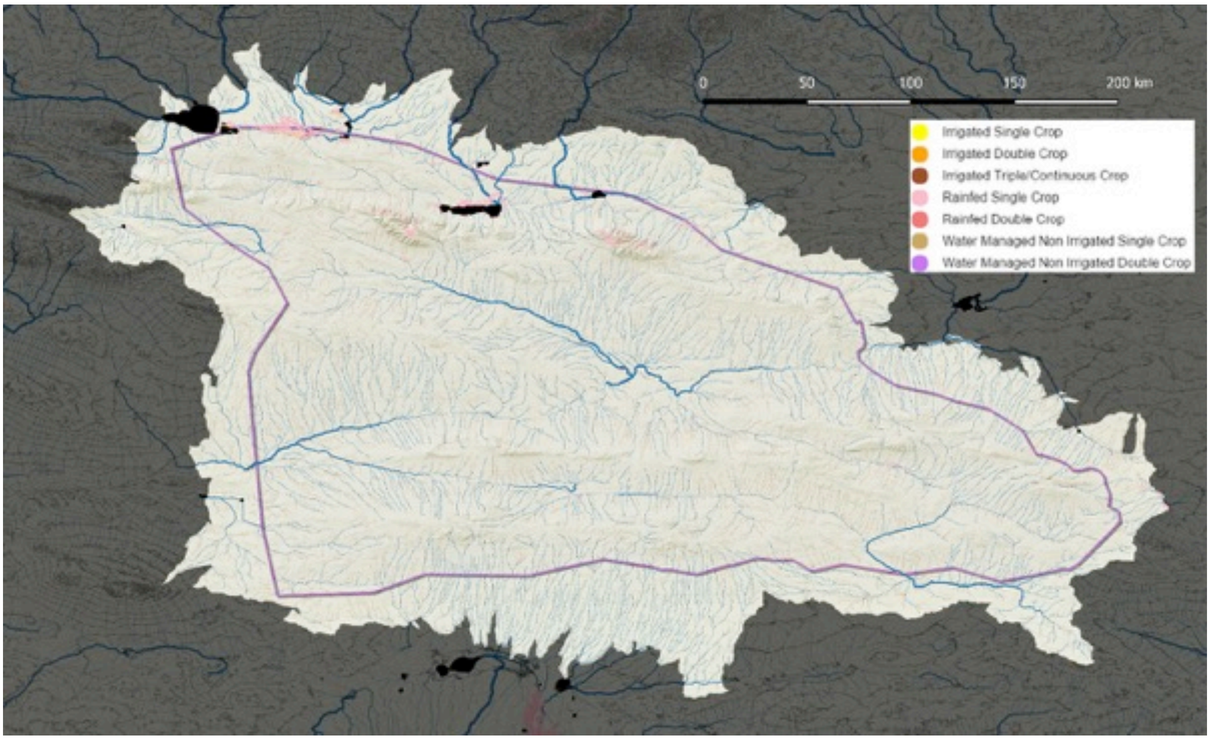


Subbasin context; human settlements



Population densities and the number and size of settlements are rural and very minimal in this landscape.

Irrigated Area Map Asia (2010)



Analysis

Only rainfed agriculture is taking place inside the landscape in the valleys of some of the streams and rivers. In general, the climate is too dry and inter-annual varibility too large to facilitate rainfed (or irrigated agriculture). Rainfed agriculture mainly takes place in those valleys of intermittents streams that have a connection to a relative large upstream area; any precipitation in such a large upstream area would find its way to those valleys, this is a way of dealing with such variability in arid climates. Yet, in wet years, these areas will be flood-prone as well, and have to risk that all agricultural infrastructure will be flushed away.

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/

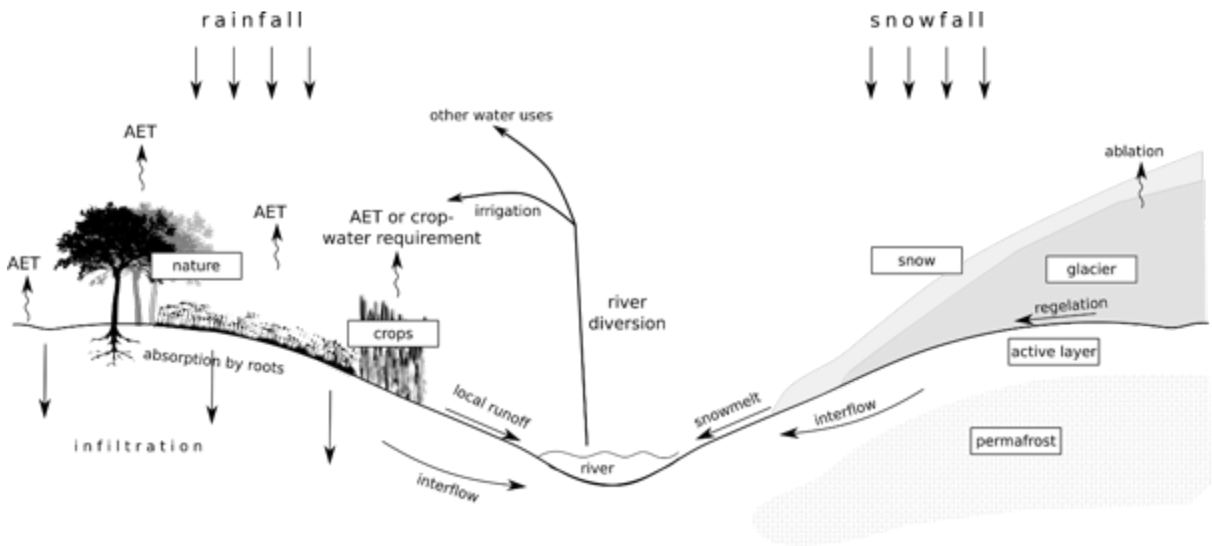
Water provision functions

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.

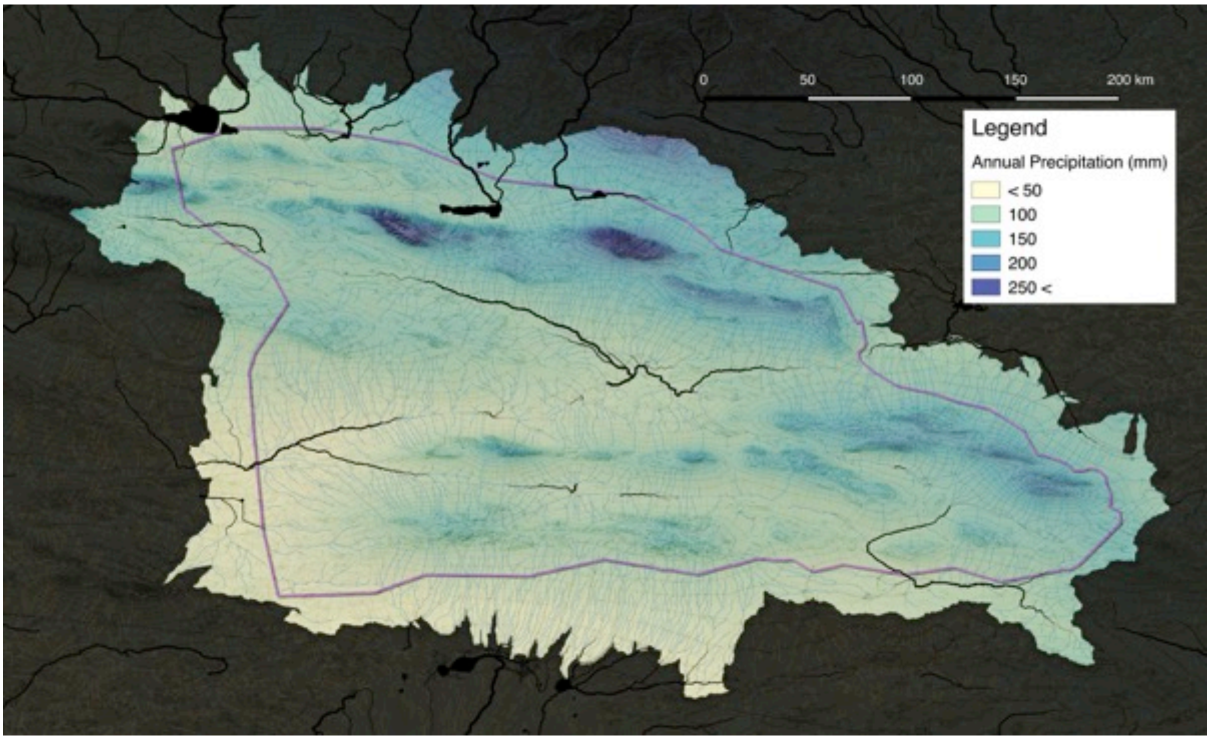
The water provision functions that are listed below are acknowledged to be of certain importance to water provision and can be mapped out, but at the moment lack essential scientific insights to be incorporated as water provision functions for any of the landscapes.

- **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.

Water provision functions; precipitation



Analysis

Since the is a desert landscape, mapping of monthly water balance does not provide relevant insights. Instead, a simple precipitation map illustrates the role that the mountain ranges play in feeding the intermittent streams and groundwater recharge.

In general, it is expected that precipitation shows high variability between the years, this means that mean values do not provide a realistic pattern of water provision.

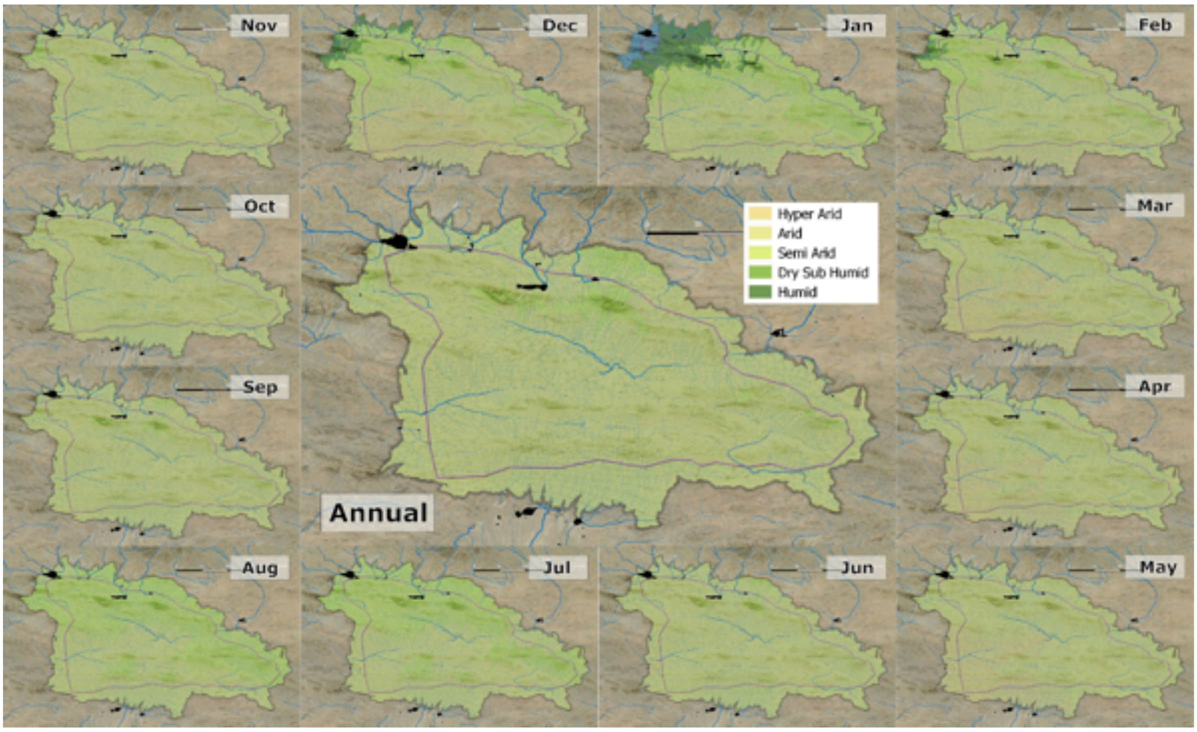
Methodology

This is a map of annual precipitation in the landscape. It illustrates the role of the mountaintops in the provision of water to the valleys downstream.

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

Water provision functions; aridity



Analysis

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

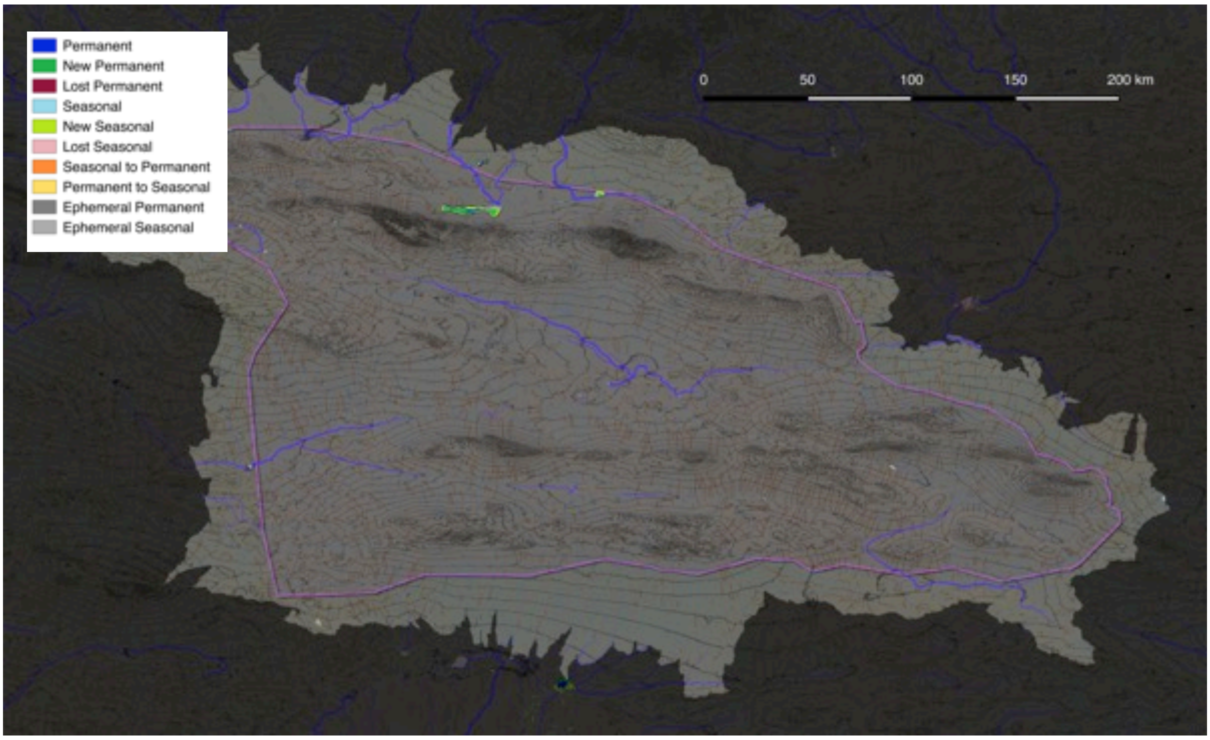
Data

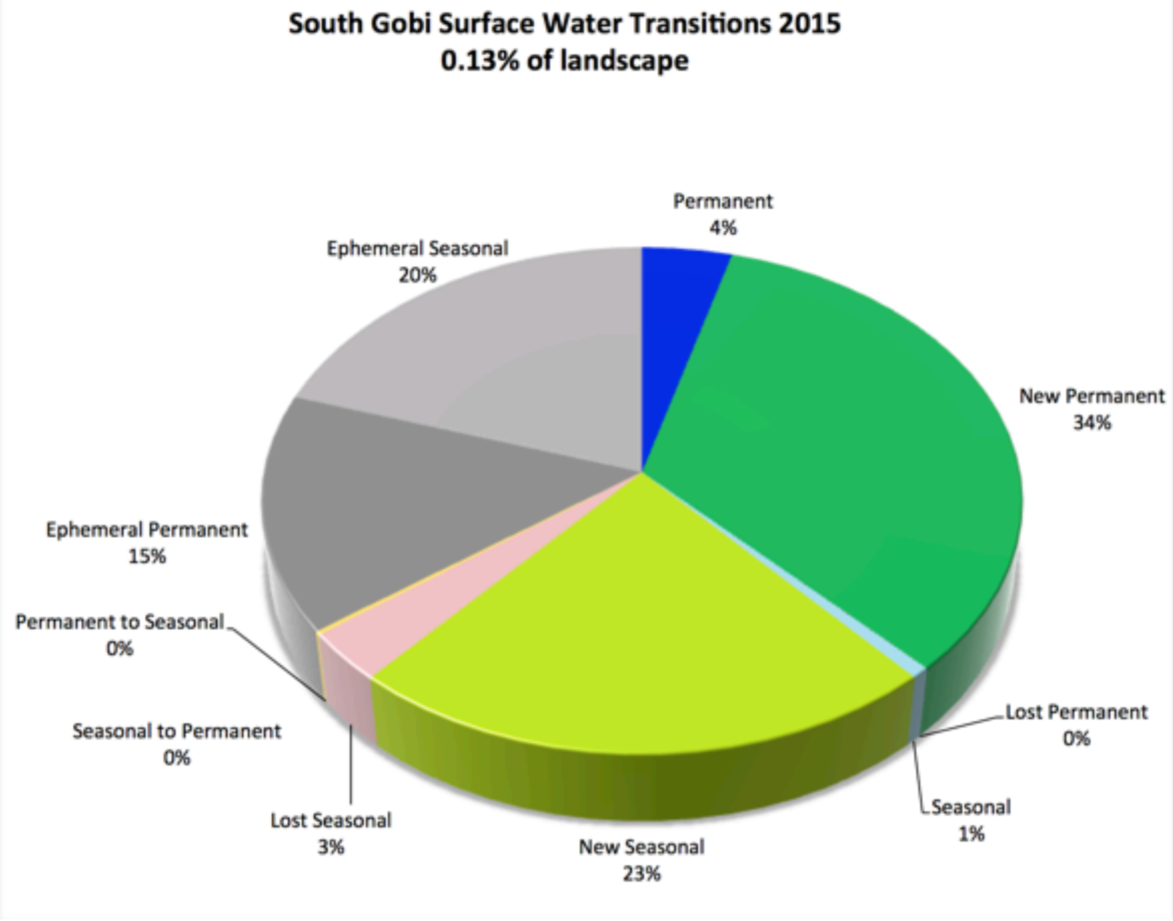
Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

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; Global surface water transitions (1984-2015)





Overview

Inside the landscape; according to the most recent map of global surface water (Pekel, 2016) only 0.13% is classified as open surface water; it can therefore hardly be identified in the above map. The following transitions occurred between 1984 and 2015:

- 40 % of the open water surface was *stable* (permanent 4 %, seasonal 1 %, ephemeral 35%)
- 3 % of the open water surface *disappeared* (permanent 0 %, seasonal 3 %)
- 57 % classified as *new* surface water (permanent 34 %, seasonal 23 %)

These are very significant shifts which can mainly be explained because of a supposed increase in the precipitation over the period 1984-2015, because there are no other water sources like glaciers or permanent snowfields located in the subbasin.

The global HydroLAKES database (Messager, 2016) detects four 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)
Taatsiin Tsagaan	16.91	19.09	39.37	2.3	1235	9006.4
unknown	0.61	4.03	1.16	1.9	1253	160.4
Orog	114.13	73.16	478.67	4.2	1216	12072.6
unknown	0.35	3.23	0.58	1.6	1767	1584.4

From Wikipedia, 2017:

"*Böön Tsagaan Lake and the nearby Taatsiin Tsagaan Lake, Adgiin Tsagaan Lake, and Orog Lake, are collectively designated a Ramsar wetland of international importance under the name "Valley of the Lakes". The valley stretches 500 km long, has a width of approximately 100 km, and is located at altitudes ranging between 1000 and 1400 meters above sea level. The topography is dominated by sandy and rocky plains and there are several lakes (the largest being Böön Tsagaan Lake and Orog Lake), solonchaks and takirs present.* "

The snowleopard landscape therefore contains a large part of Valley of the Lakes wetlands, since it is Ramsar designated, it is of global importance. The global surface water database shows that these wetlands have been in constant transition from 1984-2015.

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:

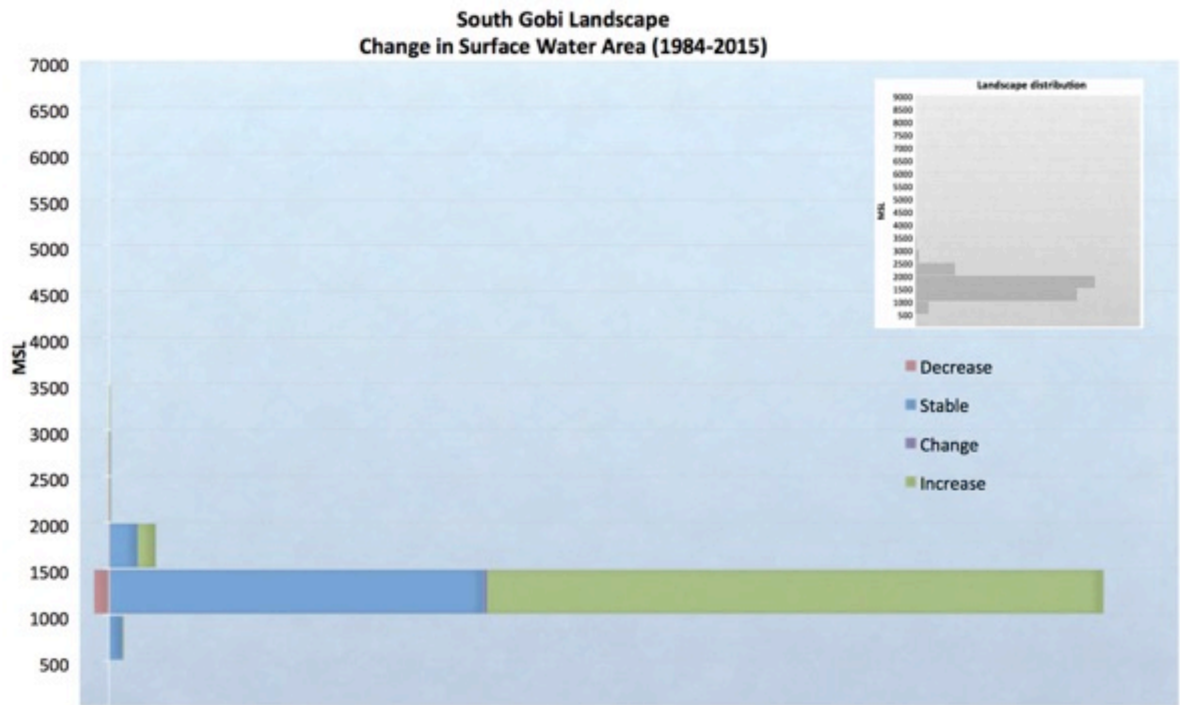
"The Water Transitions map documents changes in water state between the first year and the last year of observation. It documents:

- *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 database originate from the Global Lakes and Wetland Database. Since none of the lakes have names attributed to them, each record has been checked on Google Earth (2017) for names.



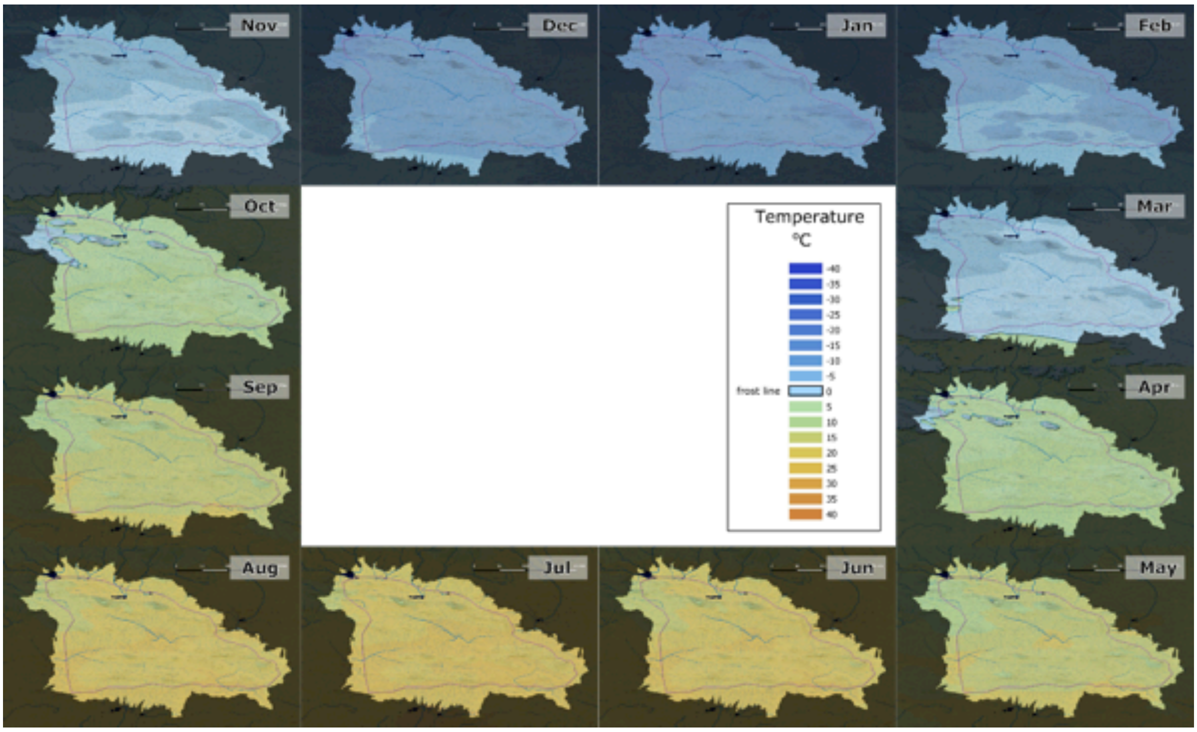
This graph illustrates for each 500 m elevation zone, what the surface water transitions are. The largest parts of the landscape is between the 1000-2000 meter elevation (see inset). The largest surface water areas are found between 1000-1500 meter, this is mainly a single water body; Lake Orog. Lake Orog is an endorheic lake, which means that it is the endpoint, the most downstream, of several rivers and streams. What happens to the lakes is therefore a product of its upstream water balances *and* the lake surface balance. The graph shows a dramatic increase in surface area of around 250 % on the baseline. This is most likely the result of increased precipitation (and runoff) in the upstream, and *not* of decreased evaporation (temperature) of the lake surface

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; frost line



Analysis

The freeze line moves fast over the months of April and October; one month the landscape is above freezing point, the next month, the entire landscape moves below zero; and vice versa. The freeze only remains a month or two longer in the mountain tops.

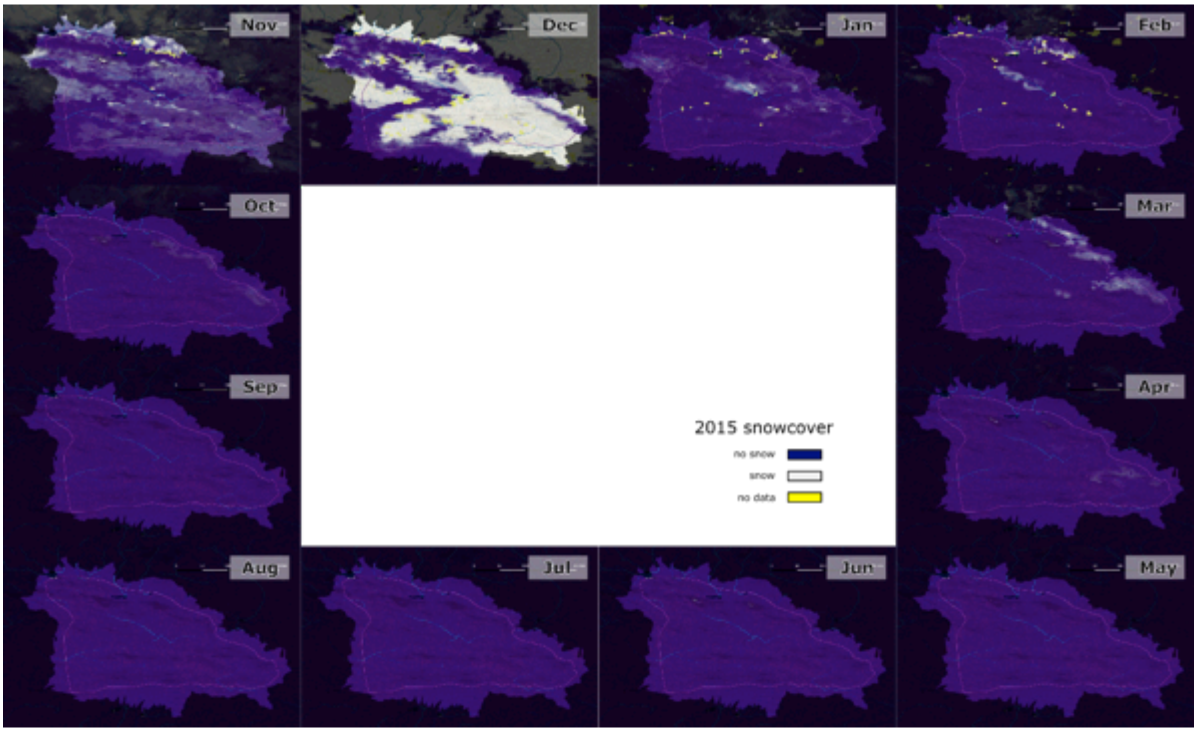
Methodology

This is a map of WorlClim mean monthly temperatures at 30s resolution with the frost 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 map 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.

The December 2015 snowfall occurrence is the so-called *white dzud*; a recurring climate extreme (of extreme cold, or snow) which precedes the mass-starvation of cattle (http://reliefweb.int/disaster/cw-2016-000004-mng).

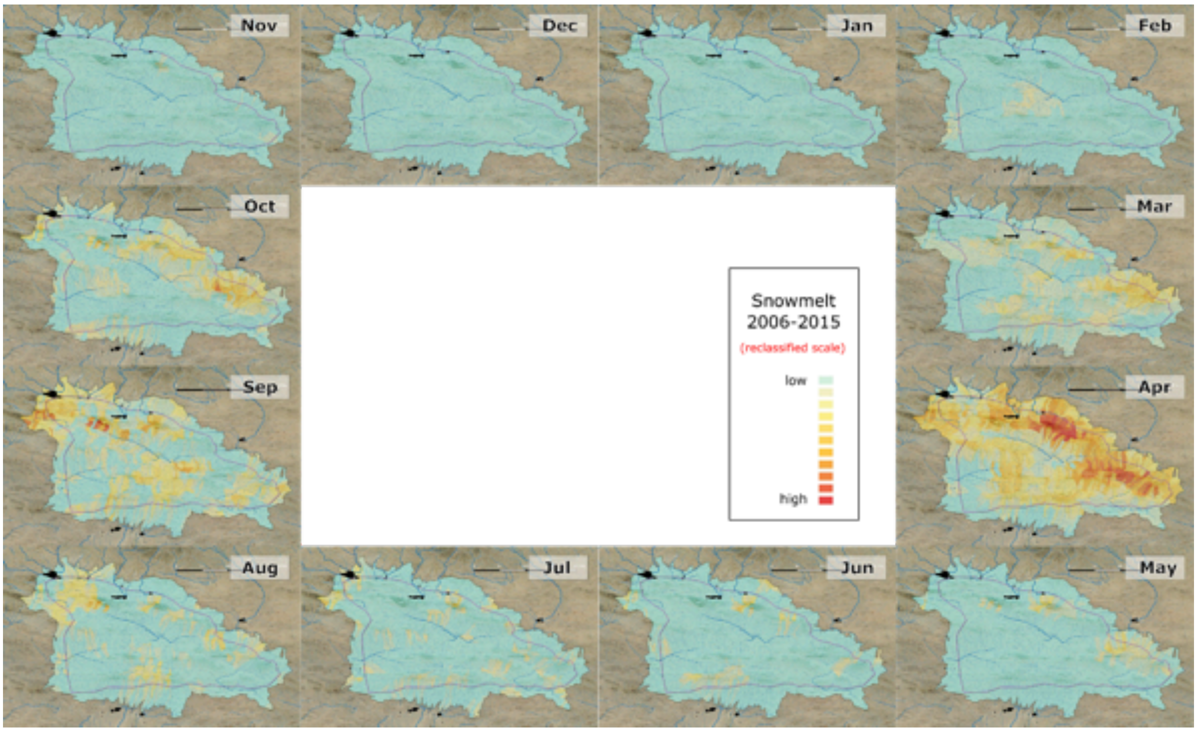
Methodology

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; snowmelt



Analysis

Subbasin and landscape context

Like any precipitation, snowfall, wind drift, and snowmelt are very variable over the seasons and variable between the different years. The map shows snowmelt quantities over the 2006-2015 period. The main snowmelt events take place in the month of April, where the mountain ranges play an important role as source of snowmelt. This might be because they capture moresnowfall, but possibly also because they capture snow that is blown from the plains during the winter months.

Also in September- October there is some snowfall reported; this might be because some parts of the early snowfall might still melt off before the winter season.

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.

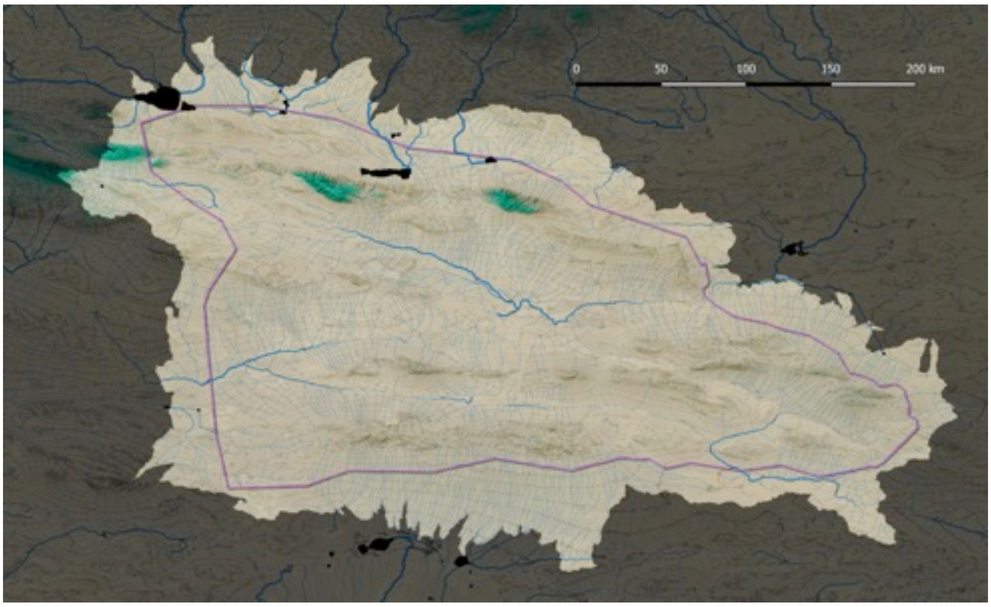
The mean snowmelt is then summarized in a GIS for each month by the selected HydroBASIN level 12 watersheds, and multiplied by each watershed area (in order to calculate quantities), both for the entire basin and the snow leopard landscape.

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; permafrosts



Analysis

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).

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.

The permafrosts here are located at the highest elevations in the mountain ranges; which are also the most important runoff areas. Any change in permafrost cover, or depth would result in changed runoff patterns, though it would be difficult to predict how these would change. These changes will become more dramatic at the frontier between permafrost and non-permafrost lands, and towards their downstream.

Methodology

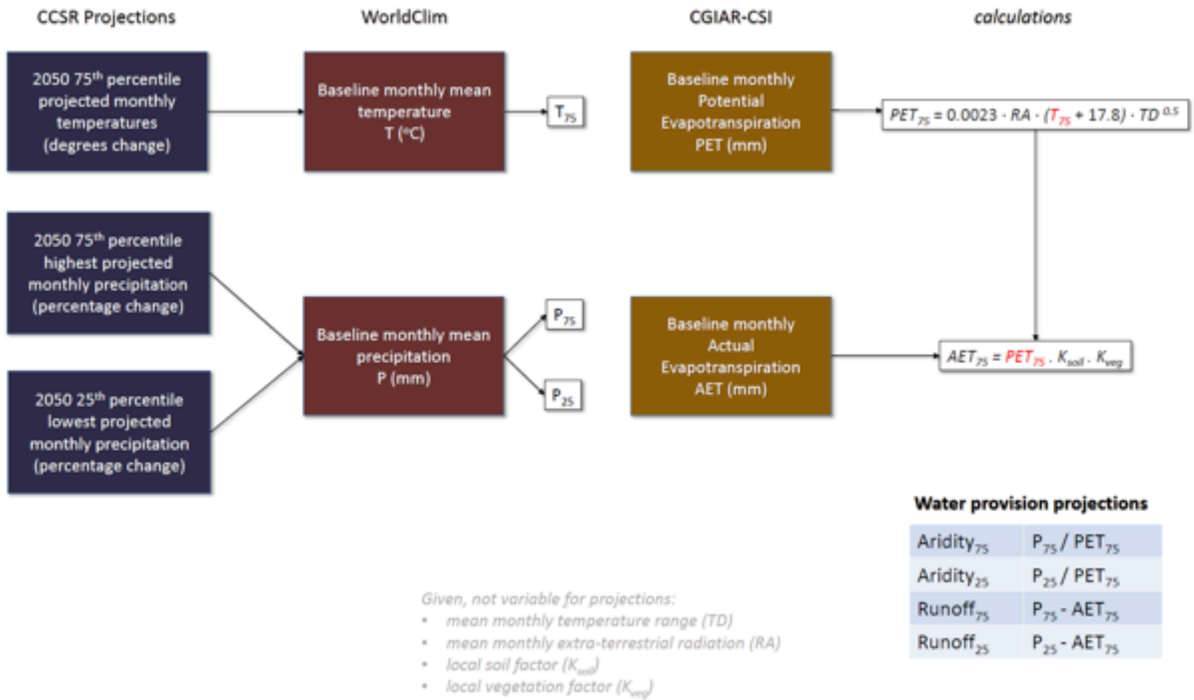
This is a map of the PZI database.

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/

South Gobi 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.

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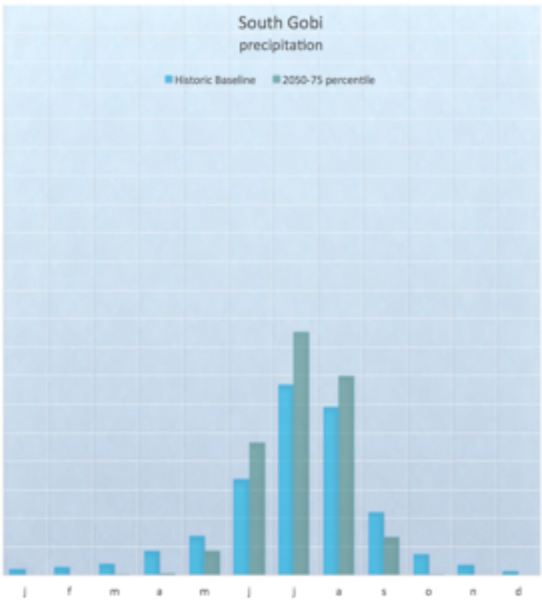
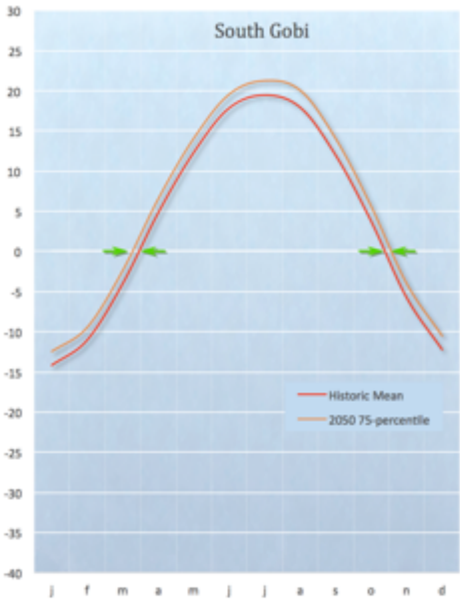
Precipitation and temperature projections



Historic precipitation compared to 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:

- The precipitation projection has difficulty in capturing reliable patterns of change since it provides relative change in percentages, so cannot model increased precipitation on a location that historically received zero precipitation. It therefore underestimates overall increase in precipitation, especially on both shoulders of the curve (March to May and September to November).
- The increased temperature will result in a shortened winter; earlier onset of spring and a longer-lasting autumn. Yet due to the steep slopes of the temperature curves in spring and autumn *this average shift* will be a few weeks, not more than a month.

Data

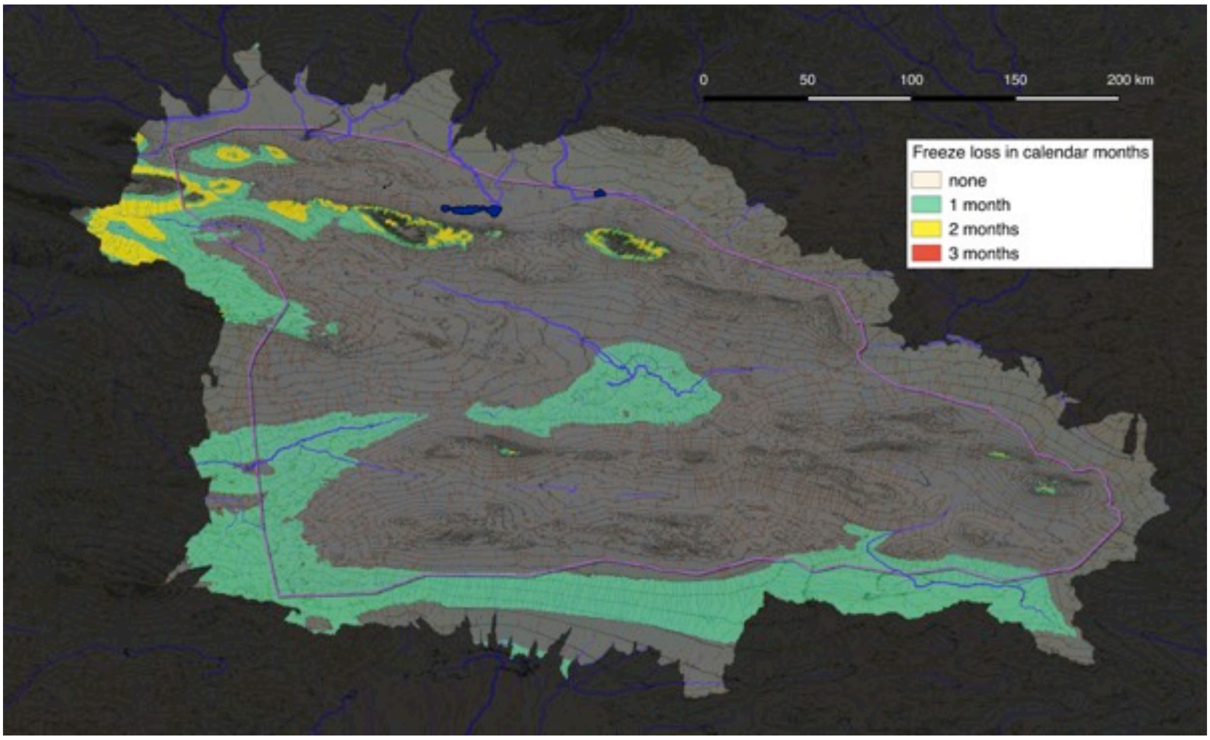
Current Mean Monthly Precipitation, based on historic WorldClim, 30s resolution; Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. www.worldclim.org

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.

Decrease in monthly freeze extent under temperature rise

Calendar months of freeze-loss



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.

Around the mountain ranges, areas will loose up to two months of winter under projected climate change. The mountaintops themselves will not loose any duration in winter; they seem to be too cold to thaw, even under increased temperatures.

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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