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NLI Colony, Jutial Gilgit

Climate Change in the Northern Areas Pakistan
Impacts on glaciers, ecology and livelyhoods

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This report was compiled by Julian Zeidler and Manuel Steinbauer as part of their internship with the WWF in Gilgit, Pakistan during March and April 2008. Full responsibility for all content as well as all rights remain with the authors.

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If you work on related subjects and are interested in future collaborations or combining our work with your findings for publishing in international journals we are always open to suggestions.
If you should be interested in what we are doing right at the moment please refer to our personal sections at www.global-change-ecology.de

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Summary

Climate change is taking place in Northern Areas. For the valley stations like Gilgit, Bunji, Skardu and Gupis an increase in mean temperature was observed for the period 1980 to 2006. The maximum increase of 0.44 °C $decade^{-1}$ was found in the winter month. Summer temperature however is declining at a rate of 0.26 °C $decade^{-1}$. Except of Gupis, no significant ($p < 0.05$) precipitation trends could be observed over the same period. Gupis had a dramatic increase in precipitation of 157mm $decade^{-1}$. This is a four-fold increase of mean precipitation between 1980 and 2006. Meteorological data for high altitude elevations are unfortunately neither available to the scientific community nor published, even if they exist from two independent sources. .
The general change of glacier extend is different in the Karakoram compared to observations for the majority of glaciers on the globe. While, in the rest of the world, glaciers are retreating dramatically (Lemke et al. 2007), a large number of glaciers in the Karakoram central ridge are stable or even increasing (Hewitt 2005 and 2007). Remote sensing data evaluated by Haritashya et al. (2007) indicate an advancing or similar terminus position for 45% of the studied glaciers. These glaciers mostly originate above 7000m and have elevation ranges of more than 4500m. They differ in size, elevation and latitude from glaciers that are used to demonstrate contemporary global change in glaciers (WGMS 2008 and Hewitt 2005). The small to medium sized Karakoram glaciers more often than not show retreating tendencies similar to the global pattern. Smiraglia et al. (2007) suggests, that especially debris covered glaciers in the Karakoram could be responsible for the different behavior.
The Karakoram Mountains have been shown to be the region with the most surge type glaciers in the world (Hewitt 2005). Surges are events of very fast glacier increase and subsequent decrease. They bear potential danger, as valley blocking could dam rivers and subsequently cause glacier outburst floods. Hewitt (2007) does not believe that changes in mass balance induced by climate changes alone could initiate surges in glaciers beeing inactive for decades. He suggests that a critical threshold had been crossed.
A questioning conducted in rural villages indicates that current temperature increase has an overall positive effect on agriculture. However future impacts can only be suspected and assessing the combined effect of social and climate changes is a major task for the future. Downscaling Global Climate Models projections done by the Global Change Impact Studies Centre in Islamabad proclaim an increase in mean temperature of roughly 4 °C for the period from 1990 to 2080 for the widely used A1B scenario. For comparison the annual mean temperature in Gilgit, Islamabad and Lahore is 16 °C, 21 °C and 24 °C, respectively. So the prediction will have a sever impact on livelihood.
The largest uncertainties where identified in assessing the reaction of ecosystems to climate change. Besides climate change, ecosystems in Northern Areas are under threat by timber extraction, overgrazing, construction works and other land use changes. With ecosystems being the basis for economic and cultural practises in Northern Areas Pakistan more effort has to be spent on assessing potential dangers related to the reaction of ecosystems on social and climatic changes.

1 Introduction

Natural beauty, topographic heterogeneity and a large diversity of cultures and languages have always attracted scientists to conduct research in the Northern Areas. However, up to now this research was often uncoordinated and went unnoticed by locally working agents like NGOs. The synchronous establishment of two expensive automated weather stations in the same location by two different research institutes (see chapter 2.4) demonstrates the need for better coordination and joined efforts.
Climate change and its influence on mountain region is currently an important topic on the international agenda. On the local scale NGOs like the WWF are willing to implement adaptation and mitigation strategies for the Northern Areas. However, detailed knowledge about ongoing changes and possible future problems is rather sparse.
This work will bridge the gap between scientific research and practical working NGOs. It aims to provide an all encompassing overview about recent scientific studies and findings concerning climatic change and in Northern Areas Pakistan. It summarizes the current state of glacier research and highlights possible linkages to climatic changes.
Possible effects on the livelihood of rural communities in Northern Areas are investigated and future problems discussed. Large scientific gaps have been identified in monitoring and predicting the reactions of high altitude mountain ecosystems on climate changes. A discussion on possible future chances and problems related to climate change as well as suggestions for urgently needed actions rounds of this report.
In the tradition of the German research society, this work is based on "the shoulder of giants". It is based on a long tradition of sound scientific research in the Northern Areas Pakistan and on other summarizing papers above all the report by Khan (2004).

2 Climate change

2.1 Global temperature trends

The Fourth Assessment Report (2007) published by the Intergovernmental Panel on Climate Change (IPCC) shows an increase of the global mean surface temperature of 0.74°C ±0.18°C over the last hundred years (1906-2005). However this warming has neither been steady in a temporal and spatial context nor the same for different seasons. The decadal rate of warming averaged over the last 50 years is nearly double that of the last 100 years (0.13°C ±0.03°C compared to 0.07°C ±0.02°C, illustrated in figure 1). Instrumental observations over the last 157 years also shows the year 2005 to be the hottest year on record and eleven out of the last twelve years (1995 to 2006) to be in the twelve hottest years on record (Trenberth. et al. 2007). Further the IPCC report states, that the temperature over the continents has risen at twice the rate of the oceans since 1979, with a decadal warming of more than 0.27°C. The greatest increase of temperature being observed in the winter and springtime of the Northern Hemisphere. The changes in extremes of temperatures are also consistent with a climate warming. 75% of all land regions in the mid-latitudes, for which data is available show a widespread decrease in the number of frost days and cold extremes as well as an increase of warm extremes (10% percentile of 1961-1991). While in the Third Assessment Report (TAR) a decrease in diurnal temperature range (DTR) was reported based on Data from 1950 to 1993, the updated observations reveal that the DTR has not changed from 1979 to 2004, as both day- and night-time temperature have risen at about the same rate. The trends are highly variable from one region to another.

2.2 Global precipitation trends

World wide observations show that changes are occurring in the amount, intensity, frequency and type of precipitation (Trenberth. et al. 2007). These generally exhibit large natural fluctuation induced by teleconnections like El Nino and changes in atmospheric circulation patterns like the North Atlantic Oscillation (NAO). Diverging long term trends (1901 to 2005) have been reported in the IPCC. While there is a general increase of precipitation over eastern North and South America, northern Europe and northern and central Asia, it is becoming drier in the Sahel, southern Africa, the Mediterranean and southern Asia. More precipitation tends to fall as rain rather than as snow. Changes in climate directly affect precipitation in different ways. On the one hand temperature warming accelerates land surface drying and increases the potential incidence and severity of droughts, while on the other hand physics (Clausius-Clapeyron relation) dictates that the water-holding capacity of the atmosphere increases by about 7% for every 1°C rise in temperature. Over the 20th century, based on changes in sea surface temperatures, it is estimated that atmospheric water vapor increased by about 5% in the atmosphere over the oceans. This is in agreement with a warming of 0.74 °C. As precipitation mainly comes from weather systems that feed on the water vapor stored in the atmosphere, this has generally increased precipitation intensity and the risk of heavy

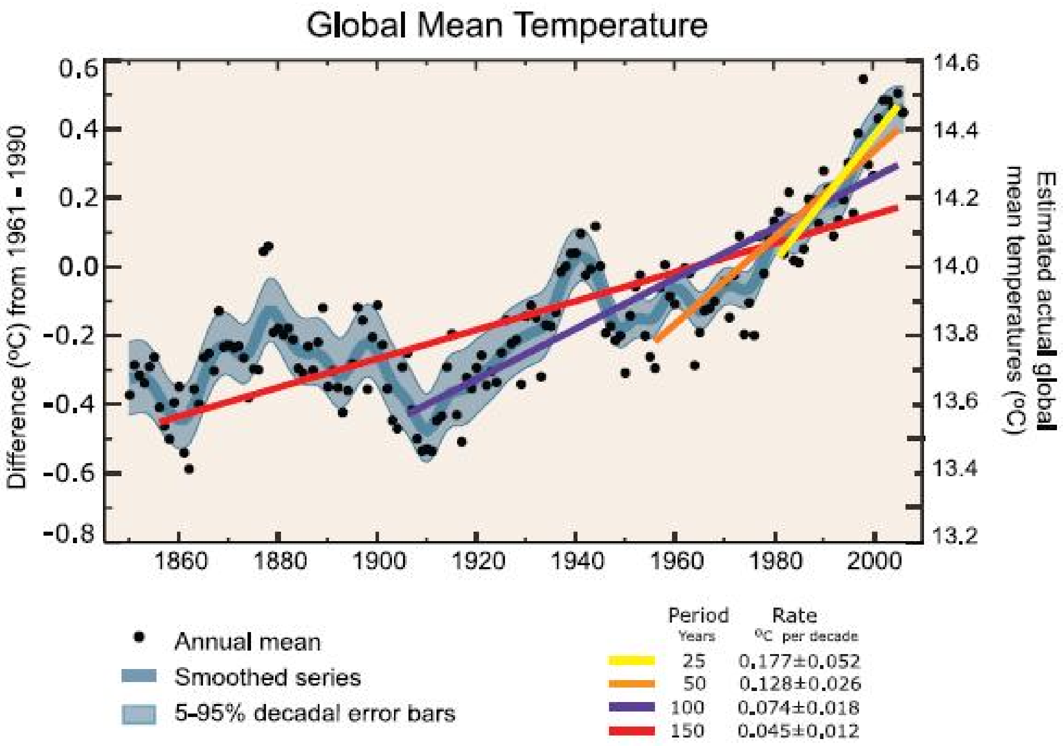

Figure 1: *Derivation of Global Mean Temperature compared to 1961-1990 (Trenberth. et al. 2007)*

rain and snow events. "Basic theory, climate model simulations and empirical evidence all confirm that warmer climates, owing to increased water vapor, lead to more intense precipitation events even when the total annual precipitation is reduced slightly, and with prospects for even stronger events when the overall precipitation amounts increase. The warmer climate therefore increases risks of both drought - where it is not raining - and floods - where it is - but at different times and/or places" (Trenberth. et al. 2007). Satellite observations of snow cover area from 1966 to 2005 show a decrease in almost all regions of the Northern Hemisphere of 5%, especially in the spring and summer month. The only month not showing any decrease are November and December. The regions affected by a decrease are mostly dominated by temperature, while regions where snow cover has increased are dominated by precipitation.

2.3 Climate patterns in Northern Areas

The climate in high altitude mountains is influenced by the broad global circulation patterns associated with the position in the continental mass and the proximity to the oceans (Archer 2001). During the winter and spring period the Karakoram area is influenced mainly by a broad scale weather system originating primarily from the

Mediterranean or from the area of the Caspian Sea (Singh et al. 1995) and from air mass convective storm in the pre-monsoon season (Archer 2001). According to Wake (1987) there are indications that at least some of the higher altitude precipitation is originating from westerly systems. In the winter however Archer (2001) claims that under the prevailing influence of the Tibetan anticyclone, local conditions are dominant. It goes without saying that mountain climates are also influenced on the medium and local scale by elevation, valley orientation, aspect and slope and the height and number of upwind barriers to the airflow.

2.4 Climate measurement stations in Northern Area

There are four meteorological measurement stations providing long time series for temperature and precipitation in Northern Area Pakistan. These have been collected and digitalized by David R. Archer and the scientific results are published in Archer (2003, 2004) and Fowler & Archer (2004, 2006). Early records up to 1947 for Gilgit and Skardu have been extracted from the 6-monthly daily weather reports published by the India Meteorological Department (IMD). Temperature time series start at 1903 and 1900 for Gilgit and Skardu, respectively. They are essentially complete from 1905 to 1935 and thereafter intermitted until 1947. From the 1950s onwards, the Pakistan Meteorological Department (PMD) provided daily temperature records for Gilgit and Skardu and monthly records for Astore and Bunji (Fowler & Archer 2006).
For precipitation, David R. Archer extracted daily full records for Gilgit and Skardu for the Period from 1894 to 1947 from the IMD. This data was obtained from the UK Meteorological Office. From partition onwards, the PMD provided daily records for Gilgit and Skardu and monthly records for Astore and Bunji (Fowler & Archer 2004).
A network of automated observation stations at elevations up to 4700m have been erected by the "Snow and Ice Hydrology Program" in association with the Water and Power Development Authority (WAPDA) Pakistan. Stations are situated at Babusar (4160m), Deosai (4356m), Yasin (3353m), Naltar (2100m), Ziarat (3688m), Shandur (3719m), Khunjerab (4733m), Rama (3140m), Rattu (2920m) and Ushkar (3353m) (Archer 2004).
Within the Pakistan German research project "Culture Area Karakorum" (CAK) a number of automatic weather stations have independently been installed between 1600 and 4700 m a.s.l. Apart from the usual instruments, some were equipped with ultrasonic snow depth sensors (Winiger et al. 2005). No coordination took place between WAPDA and CAK, when these stations were installed. The result was e.g. the simultaneous installation of two automated station at Khunjerab Pass within month (Winiger 2008).
Further on a weather station has been established in Urdukas (4200m) by a group of Italian and German scientists (EvK2CNR, see Mayer et al. 2006 and Mihalcea et al. 2006). EvK2CNR also plans to erect a further automated station at Naltar Valley (Maurizia Gallo 2008).
All these data are neither available for public scientific use, nor does data exchange take place. While Winiger (2008) offered WAPDA an exchange of their data for cross referencing, Siddique (2008) claims not to be aware that other stations even exist. Mayer et al. (2006), working on Baltoro Glacier south of K2, had to rely on data from Srinagar

station, 230 km away, in lack of obtainable long time data from the vicinity.
The sparse density - especially of long time records - is problematic for spatial interpretation of precipitation records. To achieve the same reliability of estimates, mountain regions require a much denser measurement network than neighboring lowlands due to spatial and temporal heterogeneity. Fowler & Archer (2004) points out that the existing PMD network is biased by the predominance of weather stations in valley floors and falls short by at least one order of magnitude of the minimum requirements defined by the Word Meteorological Organization. Mayer et al. (2006) stresses, that due to the strong influence of the jet streams in high elevations lowland stations cannot be used for estimates of rain and snowfall in the high altitudes of his investigation area near K2. This is probably true for all high altitude regions.
Nonetheless a scientific evaluation of the newer established high altitude automatic record stations has up to now only been done by Winiger et al. (2005) for the period from 1991 to 1999 and by Archer (2004) for the period 1994 to 1998.
Results presented in the following chapters are further based on analysis of time series (precipitation, maximum and minimum temperature) from 1980 to 2006 for Skardu, Gupis, Gilgit and Bunji carried out using the statistic program "R". Further incorporated are results extracted from Archer (2004), Fowler & Archer (2004) and Fowler & Archer (2006) who analyzed time series of the Upper Indus Basin (UIB) with data until 1999 (Bunji, Gilgit, Astore and Skardu). Investigations by Winiger et al. (2005) and Archer (2004) mainly aim at the altitudinal variability of precipitation and temperature, while Treydte et al. (2006), Esper (2000) and Esper et al. (2002) reconstruct precipitation by indirect methods on a millennial time scale.
However it must be stressed, that short term trends and variations do not reflect the underlying principles. They can therefore not be used to predict the future climatic pattern.

2.5 Temperature change in Northern Area

Temperature trends, 1980 - 2006

Mean Temperature Mean temperature for Bunji, Gilgit, Gupis and Skardu for the period of 1980 to 2006 shows an overall annual increase, with only Gilgit (Figure 2) being significant ($p<0.10$). A seasonal increase in winter (DJF) and autumn (SON) and an decrease in summer can be shown in all time series but again with a low significant proportion (Table 1 a).

Maximum temperature Significant annual increase in maximum temperature can be found in all temperature records except of Bunji (Table 1 b, Figure 3), with the average being 0.38 °C per decade. This reflects a warming in winter (DJF, Figure 3), spring (MAM) and autumn (SON). Maximum temperature in summer (JJA) did not show any significant changes.

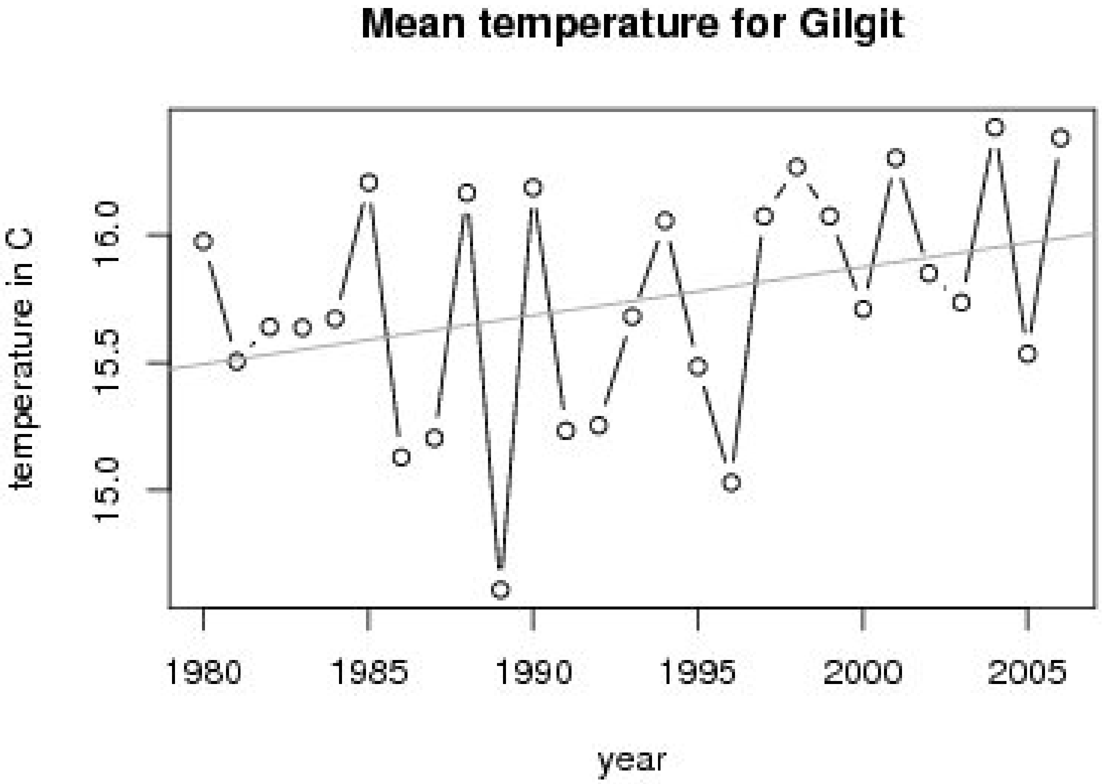

Figure 2: *Meant temperature in Gilgit for 1980 to 2006. An increase by 0.19 °C per decade has been obseved (p<0.10).*

Minimum temperature Trends in annual minimum temperature are more heterogeneous with a significant (p<0.10) decrease in Gilgit, but an increase in Bunji (Table 1 c). The cooling mainly takes place in summer (JJA). In winter (DJF) minimum temperature is indifferent or increasing.

Temperature trends, 1961 - 2000

Mean Temperature According to Fowler & Archer (2006) trends in mean temperature from 1960 to 2000 are heterogeneous for the time series Bunji, Gilgit, Astore and Skardu. Significant (p<0.05) is a decrease in mean annual temperature in Bunji by 0.52 °C decade^{-1} and an increase by 0.21 °C decade^{-1} in Skardu (Table 2 a).
For mean summer (JJA) temperature a decadal change by 0.43 °C could be shown. The change in mean temperature for the other seasons was heterogeneous with a warming trend in winter (DJF) and cooling trends in spring (MAM) and autumn (SON). For an overview see Table 2 a.

Table 1: *Trend in annual and seasonal temperature from 1980 to 2006 for (a) mean, (b) mean maximum, and (c) mean minimum, showing change in °C decade^{-1}. Bold $p < 0.05$. Italic $p < 0.10$.*

Station	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
(a) mean temperature					
Bunji	+0.22	**+0.56**	*+0.44*	-0.33	+0.18
Gilgit	*+0.19*	**+0.44**	+0.31	-0.19	+0.19
Gupis	+0.03	+0.29	+0.16	-0.47	+0.11
Skardu	+0.17	+0.45	+0.21	-0.06	+0.07
(b) maximum temperature					
Station	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Bunji	+0.11	*+0.45*	+0.34	-0.52	+0.17
Gilgit	**+0.63**	**+0.87**	**+0.79**	+0.13	**+0.72**
Gupis	**+0.41**	**+0.68**	+0.54	-0.01	**+0.51**
Skardu	*+0.37*	+0.57	+0.49	-0.02	*+0.44*
(c) minimum temperature					
Station	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Bunji	*+0.33*	**+0.67**	**+0.54**	-0.07	+0.18
Gilgit	*-0.25*	+0.02	-0.16	**-0.51**	*-0.33*
Gupis	-0.36	-0.10	-0.21	**-0.84**	-0.29
Skardu	-0.04	+0.32	-0.07	-0.10	-0.30

Maximum temperature A significant ($p<0.05$) increase in annual maximum temperature could be found for Gilgit (0.20 °C decade^{-1}) and Skardu (0.52 °C decade^{-1}). A decrease was found for Bunji (0.29 °C decade^{-1}).

Seasonal trends are again heterogeneous with an increases in winter, spring and autumn maximum temperature and a decrease in summer temperature (Table 2 b). The time series for summer and winter maximum temperature with fitted linear trend lines are visualized in figures 24 and 25.

Minimum temperature Annual minimum temperature decreased in average by 0.36 °C decade^{-1} between 1961 and 1999.

Seasonal changes indicate a decrease in minimum temperature in spring (0.20 °C decade^{-1}), summer (0.68 °C decade^{-1}) and autumn (0.56 °C decade^{-1}). For an overview refer to Table 2 c, the time series for summer and winter minimum temperature with fitted linear trend lines are visualized in figures 26 and 27.

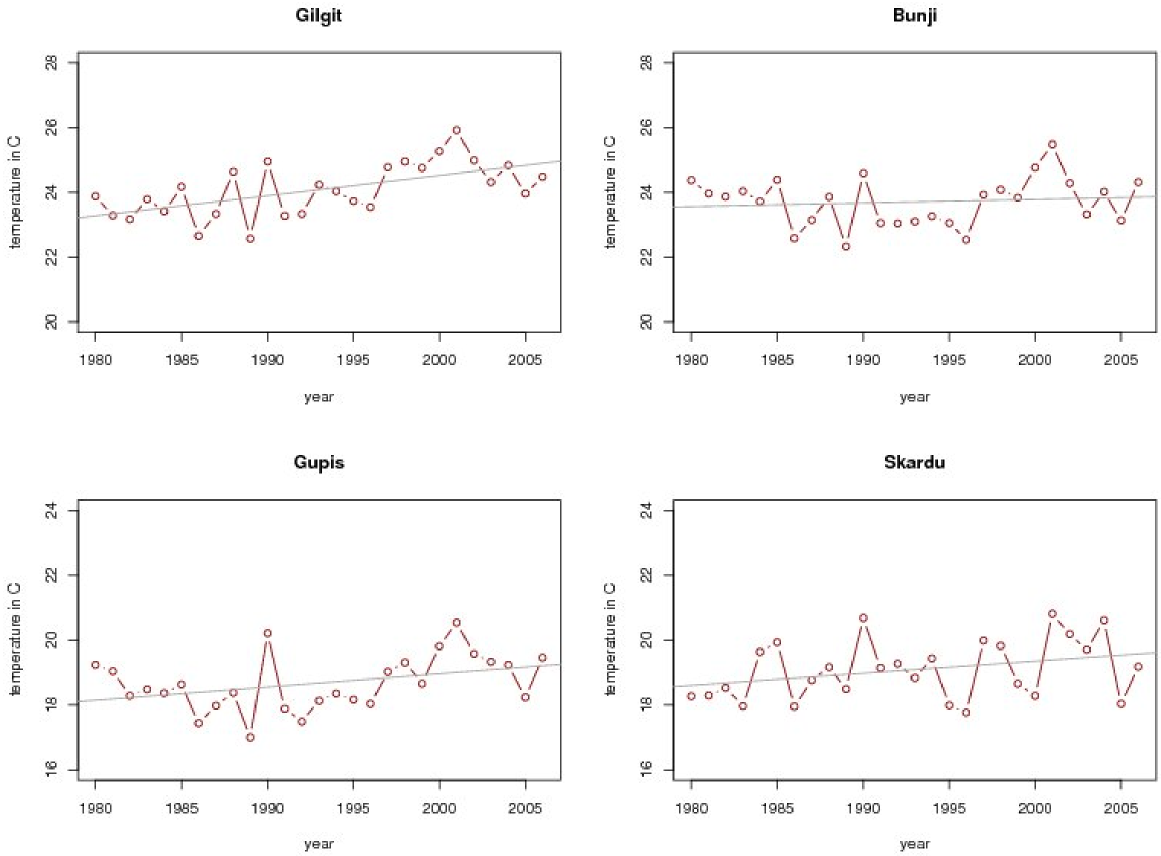

Figure 3: *An increasing trend was found for maximum temperature from 1980 to 2006. Significant (p<0.10) was a warming by 0.63 and 0.41 °C decade^{-1} for Gilgit and Gupis, respectivly, and 0.37 °C decade^{-1} for Skardu.*

Temperature trends, 1900 - 2000

According to Fowler & Archer (2006) the long time series for Gilgit and Skardu shows a warming trend in winter months related to an increase in maximum temperature and a cooling trend in summer months caused by a decrease in minimum temperature. As the time series for Gilgit and Skardu are discontinuous Fowler & Archer (2006) suggest a comparison with the correlated time series of Srinagar. This data show an increase ($p<0.01$) in annual mean temperature of 0.07 °C decade^{-1}. Winter (DJF) temperature prior to 1960 increases ($p<0.05$) by 0.10 °C decade^{-1}. Since then the rate has accelerated to 0.51 °C decade^{-1}. This change in trend might also be true for Gilgit and Skardu. Temperature time series for Gilgit and Skardu as presented in Fowler & Archer (2006) can be seen in Figure 28 and 29.

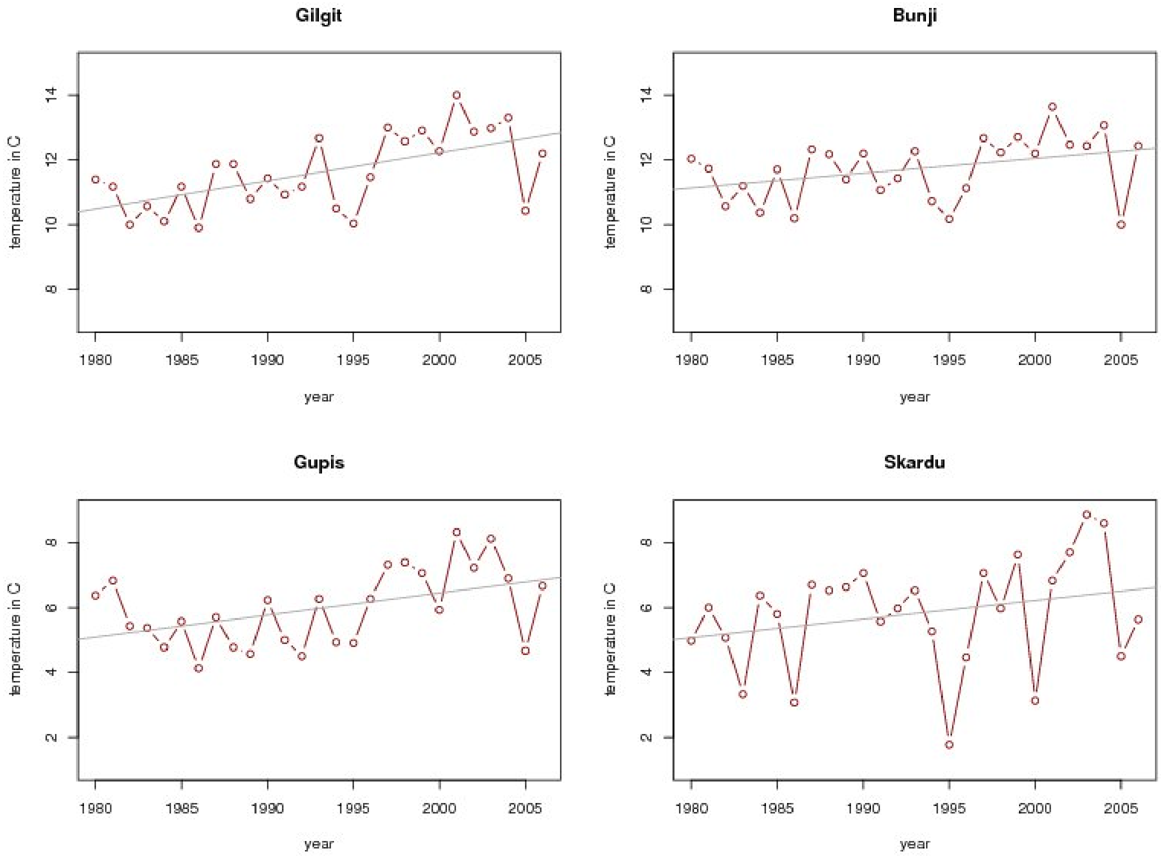

Figure 4: *The increase of mean temperature from 1980 to 2006 mainly reflects an increase in winter maximum temperature. There is a significant ($p<0.05$) warming of winter maximum temperature by 0.87 °C decade^{-1} and 0.68 °C decade^{-1} for Gupis and respectively Gilgit. The warming by 0.45 °C decade^{-1} and 0.57 °C decade^{-1} for Bunji and Skardu is only significant at the $p<0.10$ level. Please note that the scaling of the x-axis differs between graphs.*

Altitudinal temperature gradients

Archer (2004) used the available date from automated weather stations and long time recording stations for the time period from 1994 to 1998 to identify the change in temperature with elevation (Figure 7). Figure 8 illustrates the annual cycle of freezing in dependence to altitude. The investigated changes in maximum and minimum temperature will induce a change in the time period with frost on a certain elevation. Unfortunately up to now these findings have not been used to illustrate the changes that will probably influence human livelihood in the area.

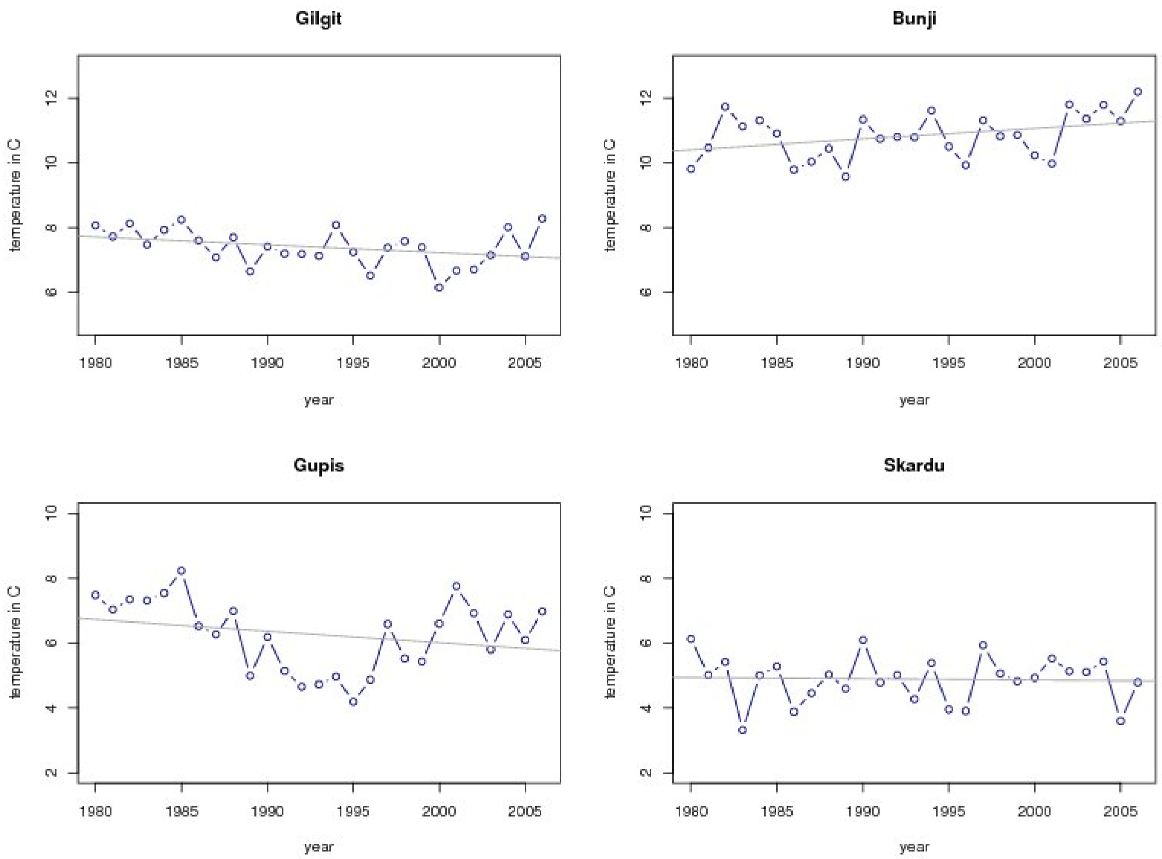

Figure 5: *A decreasing trend was found for minimum temperature from 1980 to 2006. Significant (p<0.10) was a cooling by 0.33 °C decade^{-1} and 0.25 °C decade^{-1} for Bunji and Gilgit, respectively. Please note that the scaling of the x-axis differs between graphs.*

Future temperature change

The Global Change Impact Study Centre used a assembly of global climate models for calculating a reginalised climate scenario for differend regions in Pakistan (Figure 9). They predict an increase by roughly 4 °C or 4.5 °C for the A2 or A1B szenario respectivly.

Conclusion on change in temperature

Fowler & Archer (2006) and our own findings have shown a change in the observed temperature trends from the period 1960 to 2000 in comparison to 1980 to 2006. The positive trend in maximum temperature observed for autumn, winter and spring has increased. On the other hand the significant cooling trend in minimum temperature from 1960 to 2000 observed for spring, summer and autumn is now restricted to summer only. The resulting stronger increase in mean temperature can be seen as an indicator

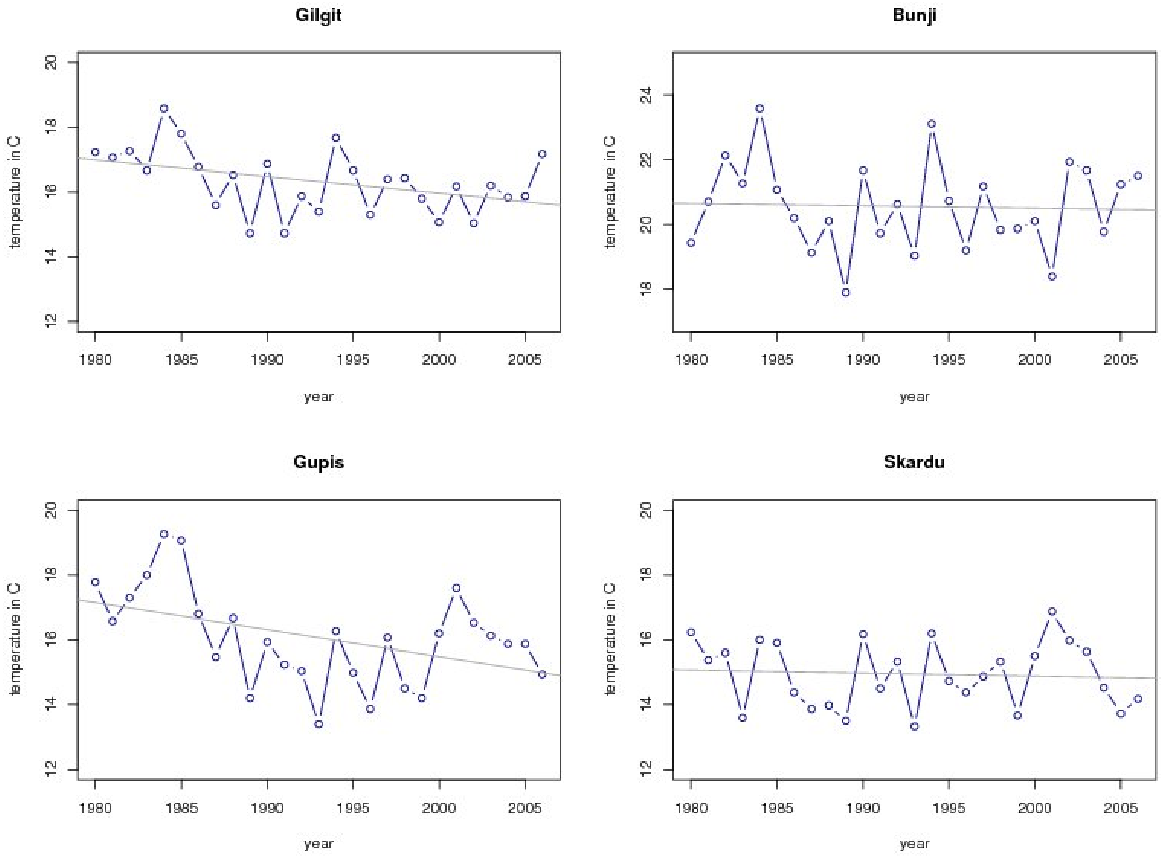

Figure 6: *The cooling mainly took place in summer minimum temperature, while winter minimum temperature does not show a significant trend from 1980 to 2006. Significant was a summer cooling of 0.51 °C decade^{-1} and 0.84 °C decade^{-1} for Gilgit and Gupis (p<0.05), respectively. Please note that the scaling of the x-axis differs between graphs.*

for an accelerating temperature rise similarly also observed on the global scale. However, the variability within the results covering in parts the same time spans also indicates a high fluctuation of the temperature time series. This underlines the fact that one has to be extremely careful when projecting trends into the future. Regional dynamic climate models or at least a statistical downscaling from global models as done by the Global Change Impact Studie Centre (see 2.5) is needed to do scientific predictions. However, a dense meteorological nework, especially for higher altitudes, is needed to drive these. Collaboration between the different institutions operating measurement stations and open access to data and results would be a large step forward.

Table 2: *Trend in annual and seasonal temperature from 1961 to 1999 for (a) mean, (b) mean maximum, and (c) mean minimum, showing change in °C decade⁻1. Bold p < 0.05. Italic p < 0.10.*

(a) mean temperature					
Station	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Bunji	**-0.52**	+0.07	**-0.32**	**-0.99**	**-0.66**
Gilgit	-0.13	*+0.17*	-0.08	**-0.38**	-0.15
Astore	-0.08	-0.07	-0.06	*-0.30*	+0.01
Skardu	+**0.21**	+**0.38**	*+0.24*	+0.05	+**0.26**
(b) maximum temperature					
Station	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Bunji	**-0.29**	+0.10	-0.20	**-0.86**	-0.16
Gilgit	+**0.20**	+**0.27**	+0.16	-0.01	+**0.35**
Astore	-0.05	-0.07	-0.18	-0.19	*+0.28*
Skardu	+**0.52**	+**0.55**	+**0.46**	+0.30	+**0.75**
(c) minimum temperature					
Station	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Bunji	**-0.67**	+0.06	**-0.47**	**-1.11**	**-1.17**
Gilgit	**-0.45**	+0.02	**-0.32**	**-0.75**	**-0.62**
Astore	-0.13	-0.08	+0.06	**-0.41**	-0.08
Skardu	*-0.17*	+0.23	-0.05	**-0.43**	**-0.34**

2.6 Precipitation change in Northern Area

Precipitation trends, 1961 - 1999

Fowler & Archer 2004 analyzed long records from Gilgit and Skardu covering the period from 1894 to 1999, with missing data in the time of partition 1947 to 1954. They found no significant annual long time trend in the records. Gilgit and Skardu show evidence of a -not significant- upwards trend since 1960 in annual precipitation. Winter precipitation shows a slight increase in pre-partition times in both stations and a continued strong upwards trend in Skardu till the 1990, which is statistically significant ($p<0.05$) and contributes an increase of 22 mm decade^{-1}. All annual, three and six months trends for Gilgit, Bunji, Astore and Skardu can be seen in table 3 as a percentage increase of the period average.

The records only shows significant increases for the summer rainfall in Astore, Bunji and Skardu, "with a decadal increase of 13, 9 and 6 mm respectively"(Fowler & Archer 2004) as depicted in Figure 10. The annual increase was significant in Gilgit, Bunji and Skardu. The spring and winter precipitation shows the highest variations, with

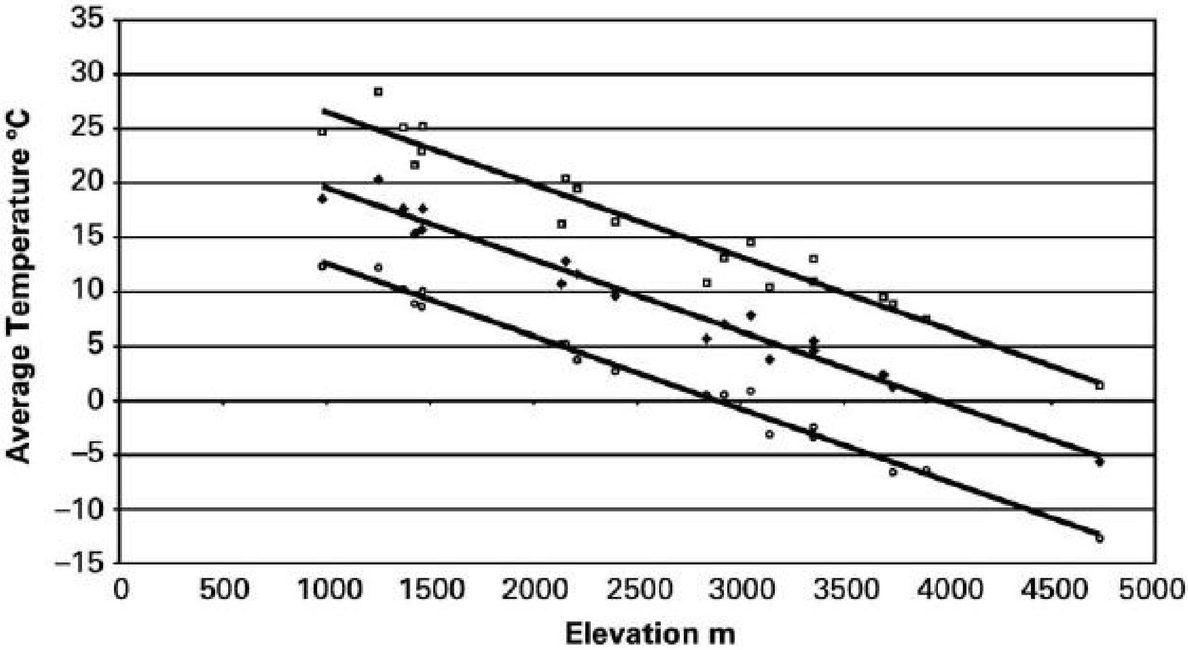

Figure 7: *Altitudinal temperature gradient for an annual and the two 6 month periods derived from the time period from 1994 to 1998. (Archer 2004)*

Table 3: *Trends in precipitation from 1961 to 1999 for annual, three and six month periods showing the change per decade as a percentage of the period average. Bold p < 0.05. Italic p < 0.10.*

Station	J-D	J-M	A-J	J-S	O-D	O-M	A-S
Gilgit	**+10**	+1	+9	+5	+11	+3	+8
Bunji	*+13*	-7	+10	**+19**	+23	+4	+14
Astore	+5	+3	-3	**+18**	+16	+5	+3
Skardu	**+14**	**+18**	+3	*+17*	+19	**+18**	+8

stations divided between increase and decrease, while the autumn shows an overall strong increase, but is not at all significant.

Precipitation trends, 1980 - 2006

An analysis of monthly precipitation data from 1980 to 2006 for stations Bunji, Gilgit, Gupis and Skardu was performed. Before doing the analysis, the sporadic negative values (-1 and -100) were set to zero, as no information was available on the meaning of these negative values. A linear trend analysis showed a significant increase ($p<0.05$) of 150mm decade^{-1} in Gupis for annual precipitation as well as for all three months sums, depicted in Figure 11. Apart from Gupis the only significant trend ($p<0.10$) can

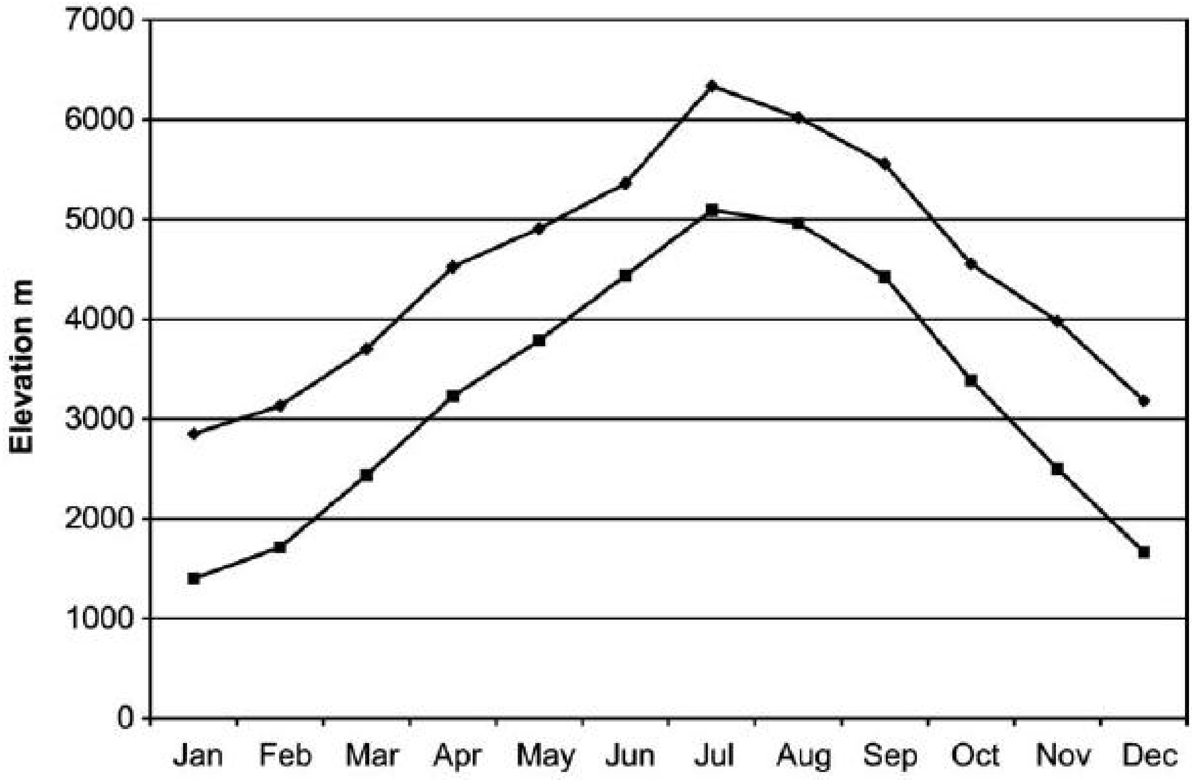

Figure 8: *The annual cycle of freezing altitude for maximum and minimum temperature will change along with temperature. A shorter frost period will probably influence human livelihoods. (Archer 2004)*

be found in the winter precipitation in Gilgit. Noteworthy is that Gupis is the only one of the four stations that shows an increase of precipitation in the winter month, with Gupis also being the station with the strongest overall increase (compare table 4 and Figure 12).

Table 4: *Trend in annual and seasonal precipitation from 1980 to 2006, showing changes in mm decade^{-1}. Bold $p < 0.05$. Italic $p < 0.10$.*

Precipitation					
Station	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Bunji	+7.67	+5.51	+1.29	+5.49	-4.26
Gilgit	+9.08	*+6.83*	+10.10	+5.58	-4.34
Gupis	**+157.66**	**+20.41**	**+78.29**	**+39.13**	**+19.82**
Skardu	+14.39	+9.49	+12.74	+3.06	-10.90

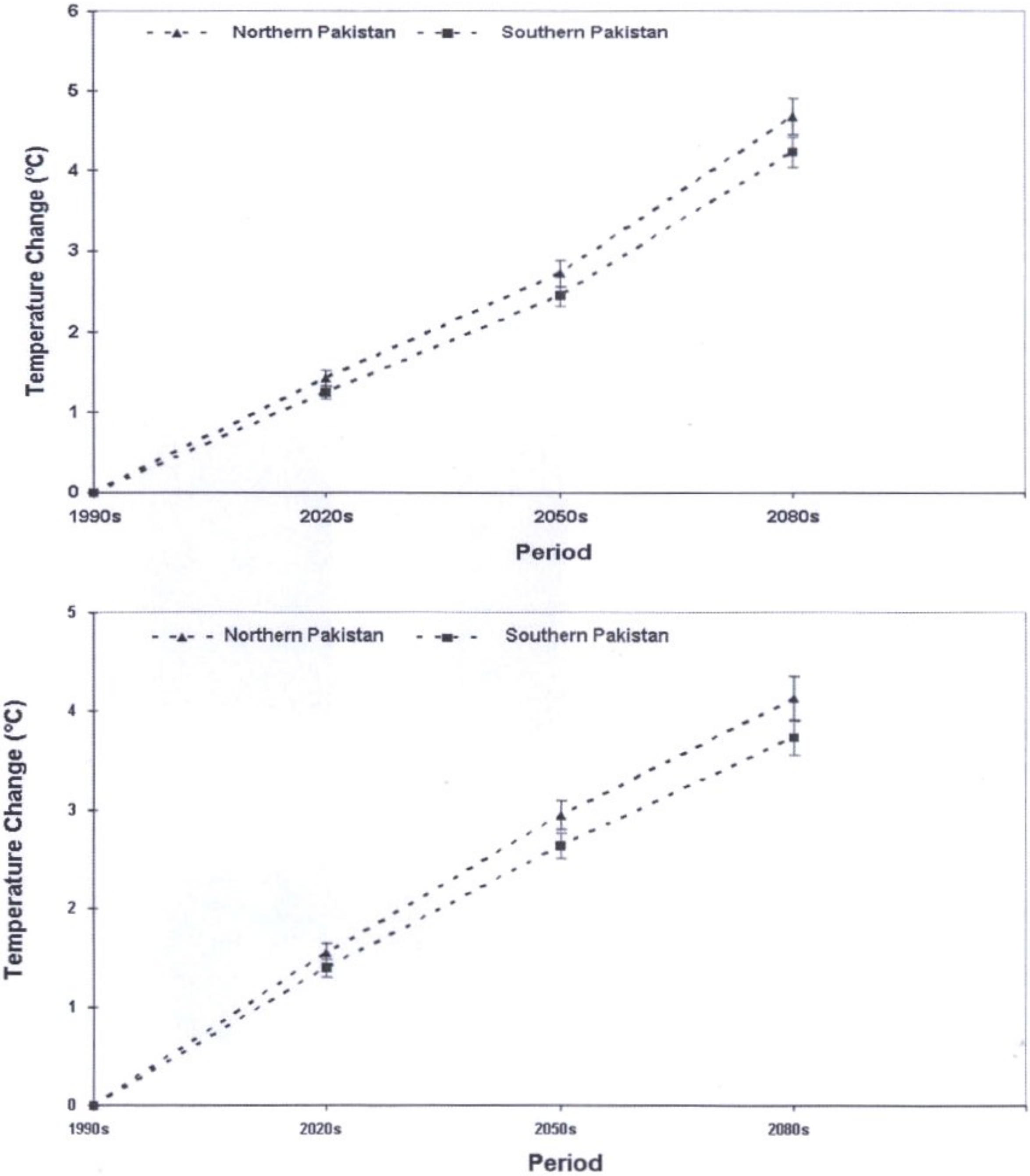

Figure 9: *Temperature projections by regionalised global climate models for a) the A2 scenario (calculated from 13 GCMs) and b) the A1B scenario (calculated from 17 GCMs (GCISC)). (Courtesy Global Change Impact Studies Centre, Islamabad)*

Millennial time scale reconstruction

Treydte et al. (2006) present a reconstruction of precipitation changes from annually resolved oxygen isotope ratio (δ^{18}O) chronologies from juniper treering cellulose (*Ju-*

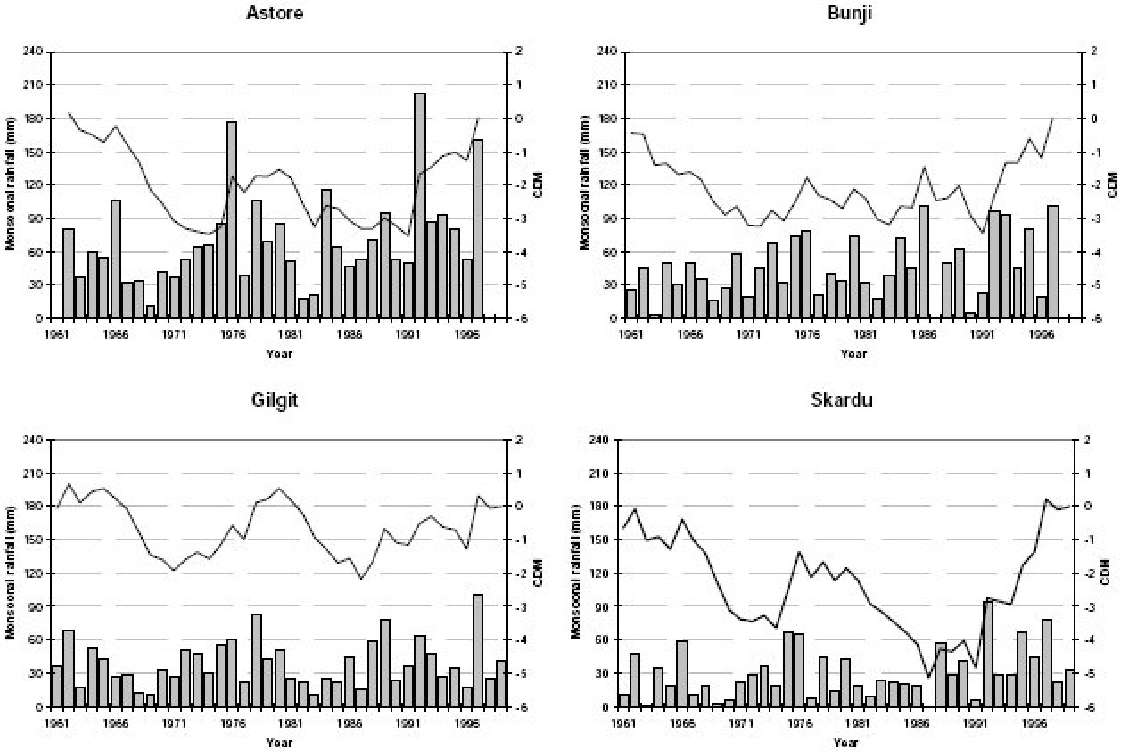

Figure 10: *Trends in summer rainfall (Jul-Sep) from 1961-1999. Panels show rainfall series (bars-left axis) with the cumulative departure from the mean plotted as a line (right axis) (Fowler & Archer 2004)*

niperus excelsa, J. turkestanica) for the twentieth century and one even extending back to AD 828. The study sites are located in three valleys south and north of the main Karakoram range on an elevation of 2900 to 3900 m. Centennial-scale variations indicate dry conditions at the beginning of the past millennium and through the eighteenth and early nineteenth century, with precipitation increasing during the late nineteenth and twentieth century, yielding the wettest conditions of the past 1,000 years (Figure 13). Treydte et al. (2006) suggest that an unprecedented twentieth-century intensification of the hydrological cycle in western Central Asia has already occurred. The climatic signal originates mainly from winter precipitation, and is robust over ecologically different sites.

Estimate of high altitude precipitation

Winiger et al. (2005) illustrates large failures in common estimates of total precipitation, especially for the high altitudes in Northern Areas. Different authors have derived very different estimates for the higher Karakoram altitudes, ranging from only 130mm year^{-1} to 1300mm year^{-1} in the zone between 4000m and 5000m (Winiger et al. 2005).

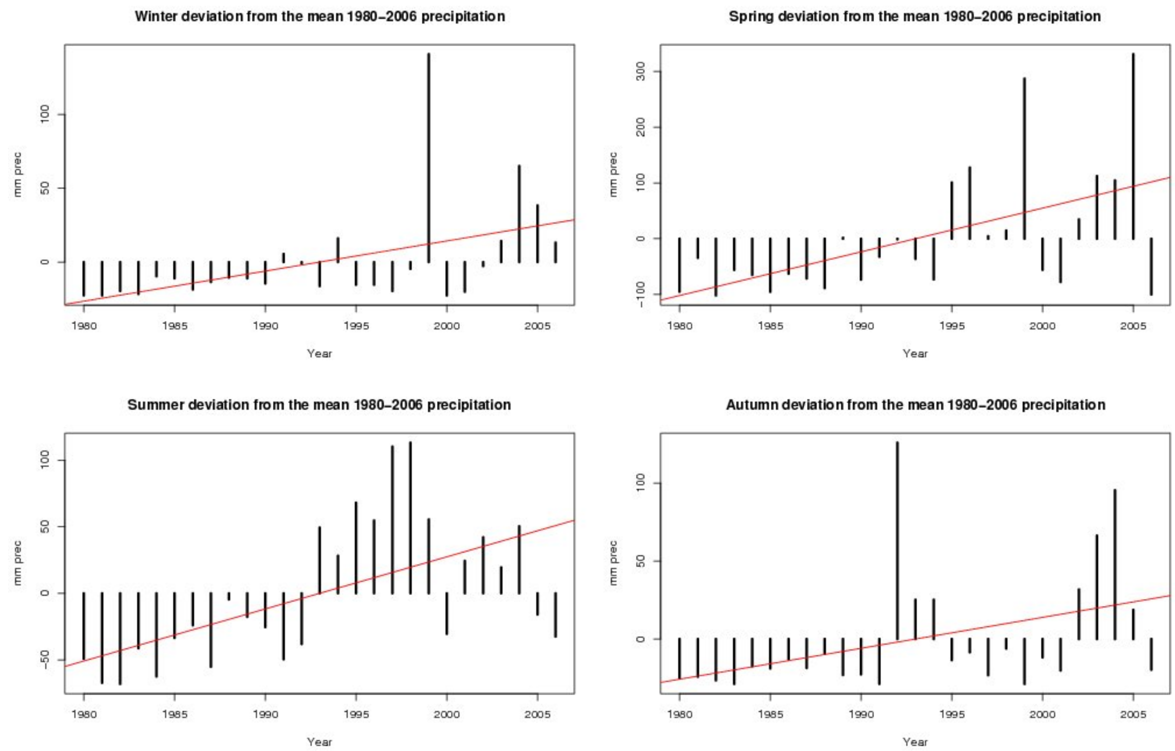

Figure 11: *Deviation from seasonal mean precipitation in Gupis 1980-2006 for winter (DJF), spring (MAM), summer (JJA) and autumn (SON), overlaid with the linear trend*

Two short term studies from the Cultural Area Karakoram program where conducted in Yasin Valley (Jacobsen 1991) and the Bagrot Valley (Cramer 1991) with climate stations over a range of altitudes. Jacobsen (1991) and Cramer (1991) showed an increase of precipitation with altitude up to the highest station at Alambar (4400m) with an annual total of 636 mm year^{-1} and 720mm at station Diran (4120m), with the year of measurement being close to average in the valley stations, according to Archer (2001). Winiger et al. (2005) used a combined snow cover and ablation model to derive total annual amounts of precipitation for different altitudinal zones. Figure 14 displaces possible relationships between altitude and precipitation. The measurements indicate that more than 90% of the annual precipitation is deposited as snow at 5000 m a.s.l., whereas in the lowest parts of the valleys snow contributes no more than 10%. It is also evident that a barrier effect intensifies the southwest/northeast decrease of precipitation.

2.7 Glaciers and glacier lakes

The Karakoram has the largest concentration of glaciers on mainland Asia apart from high latitudes, with eight glaciers over 50 km in length and more than 20 over 30 km. Because of these enormous ice masses it is sometimes referred to as the third pole. The

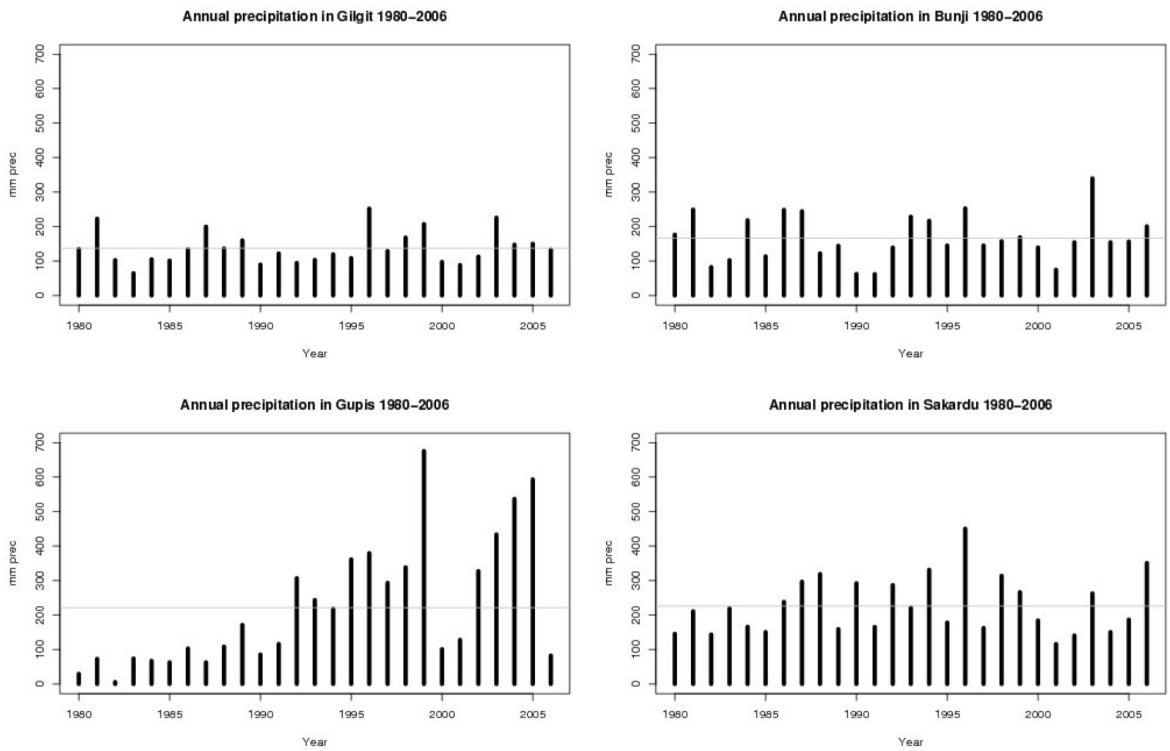

Figure 12: *Annual precipitation 1980-2006 for Bunji, Gilgit, Gupis and Skardu, overlaid with the mean yearly precipitation.*

highest of the southwest central Asian mountain systems has a perennial snow and ice cover exceeding $16,000km^2$ (Hewitt 1998).

Glacier recessions and advances

For most glaciers in the Karakoram a huge loss of ice mass and glacier recession was observed from the 1920s until the early 1990s, with exceptions for some short term advances in the 1970s and surges (Hewitt 2005 and 2007). Since then there has been thickening and advances in many non-surging glaciers, but **confined to the highest** watersheds of the central Karakoram (Hewitt 2005 and 2007). These glaciers mostly originate above 7000m and have elevation ranges over 4500m. They differ in size, elevation and latitude from glaciers that are used to demonstrate contemporary global change in glaciers (WGMS 2008 and Hewitt 2005).
Glaciers in the rest of the region continue to decline, including most valleys where the official PMD climate stations are located. The expansions in the glaciers of central Karakoram occurred suddenly and irregularly while the climate data suggest long-term, relatively small and gradual trends, but large, short-term fluctuations (Hewitt 2007).
Glaciological studies have a long tradition in the Karakoram Mountains. An overview over publications until the early 1990s can be found in National Snow and Ice Data

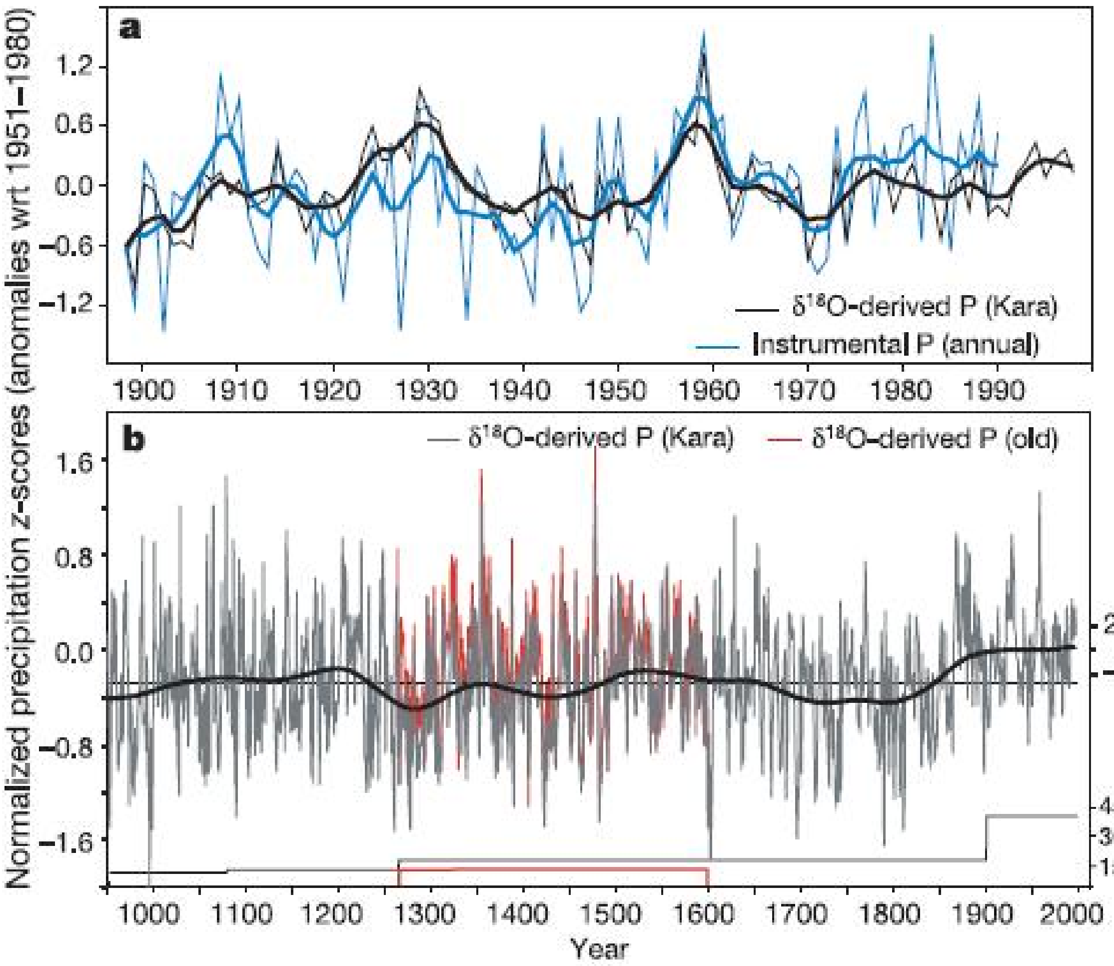

Figure 13: *Reconstruction of precipitation in Northern Areas derived from $\delta^{18}O$ treering analyses. Panel a illustrates annual precipitation values from 1898 to 1990 of instrumental and modeled data with respect to (wrt) the 1951 to 1980 mean. Smoothed curves are 5-year Kernel filters. P: precipitation.*
Precipitation reconstruction since AD 950 is shown in panel b. The horizontal line is the overall mean of the reconstruction. For the period 1264 to 1599, maximum deviations are in red when using data from only old tree-rings. Long-term variations are highlighted using a 150-year spline. Uncertainty estimates for the low frequency domain are indicated by two standard errors (see Treydte et al. (2006)).

Center (2008) and Khan (2004). More recent investigations can be used to discuss the effect of climate change on glaciers in the Karakoram:
Meiners (2006) found a retreat of Kukuar and Baltar glaciers north of Bar Valley since 1915 by eight km. His investigations where based on comparisons with Schomberg (1933), who also presented information obtained from local people, that Baltar and Kukuar glaciers had been retreating far back into their side valleys around 1833 and

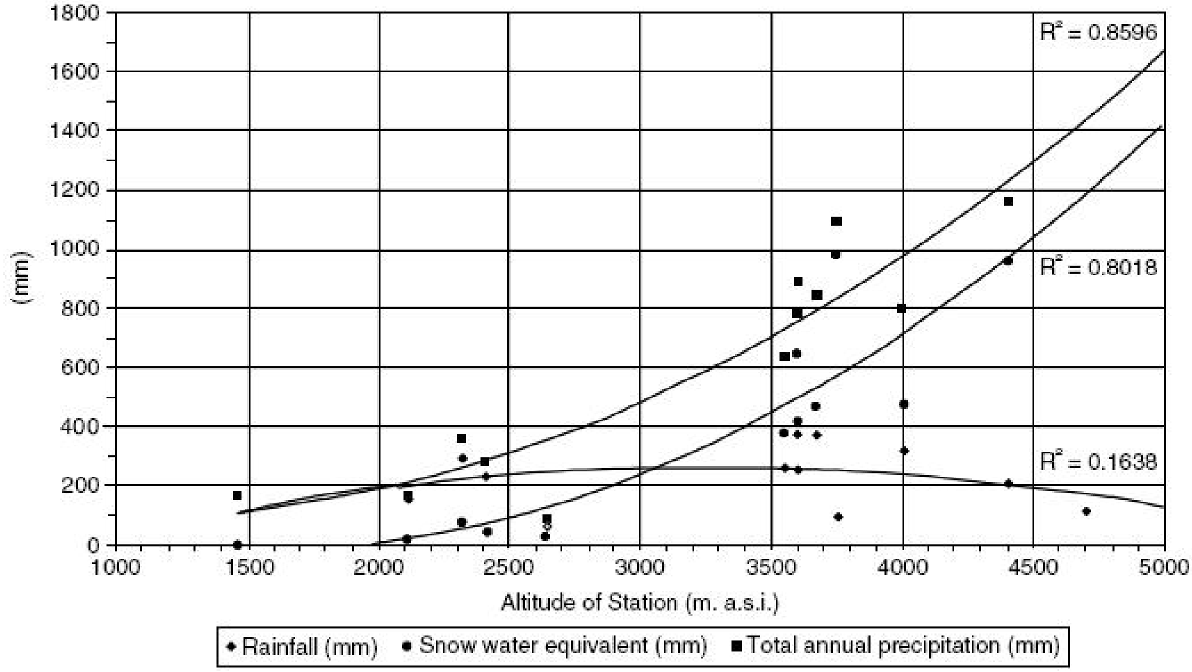

Figure 14: *Total annual precipitation (rainfall and snow water equivalent) in the Karakoram derived from a profile ranging from Gilgit (at 1500 m a.s.l.) to Kunjerab Pass (at 4700 m a.s.l.), including several locations in Yasin and Bagrot valley. Stations covered the time period from 1991 to 1996. (Winiger et al. 2005)*

advanced between 1833 and 1915 by around ten km and 670 m in altitude. Schomberg (1933) also found strong retreat tendencies of Bar glaciers and Daintar glaciers. The Daintar glacier (Kerengi) retreated 2.5 km in length and 330 m in altitude within the last 67 years (Meiners 2006). According to reports of the local population the Toloibar glacier in the western end of the valley, as well as the small hanging glaciers along the valley are retreating as well (Meiners 2006).

The terminus of Batura glacier was at the Hunza River in the late 19th and first half of the 20th century and then retreated rapidly by roughly 800 m by 1966. An ice cliff had formed at the terminus in 1966, advanced forward 100 m and thickened 15 m by 1975, and advanced another 33 m by 1978. Then by 1984 the frontal ice cliff had retreated 50 to 100 m, declined in slope angle and was covered with debris and vegetation (Goudie et al. 1984). Bulley et al. (2007), Shroder et al. (2007) and Mertes et al. (2007) used remote sensing techniques and compared the results with other investigations on the Batura Glacier. Shroder et al. (2007) found, that for the period between 1973 and 2007 the terminus underwent 392 m of retreat from 1973 to 1990 (23 m year^{-1} annual retreat rate), 36 m retreat from 1990 to 1992, (18 m year^{-1} annual retreat rate), a 37 m advance (3 m $year^{-1}$ annual advance rate) from 1992 to 2004 and a 50 m advance from 2004 to 2007.

According to Chinese mapping of Batura Glacier (Batura Glacier Investigation Group

1980) the terminus of the **white ice stream** of Batura Glacier was roughly 3.2 km from the Karakoram Highway in 1975 and then retreated to a position at roughly 5.9 km from the Karakoram Highway in 2003 (Mertes et al. 2007). Mertes et al. (2007) conclude that due to down wasting and increasing supraglacial debris cover the white ice stream has retreated 2.7 km from 1974 to 2003. Comparison with historical data shows a possible increase in the annual velocity gradient yet a decrease in the overall velocity magnitude. The general lowering in magnitude is not uniform, resulting in higher velocities in the central and upper portions of the glacier. This generates an increased altitudinal velocity gradient, compared to the gradient of 1974. They suggest positive mass balance conditions and increased ablation and downwasting in the lower terminus region.
Mayer et al. (2006) and Smiraglia et al. (2007) did field investigations on geometry, morphology, dynamic state and the ablation conditions of Baltoro glacier, with a length of 62km one of the world's largest glaciers. Observations of the glacier snout position - mainly by photograph comparison - lead to the conclusion that only minor changes occurred during the last century (Figure 15). At Concordia, situated between the upper and the lower parts of the glacier elevation differences were below 40m (with a thickness of up to 900m) in the last 95 years. Mayer et al. (2006) argue, that extensive debris cover might protect the Baltoro glacier and his tributaries from a general retreat and from surge type reactions that had been investigated for the neighboring glaciers (Diolaiuti et al. 2003 and Hewitt 2007) probably as reaction to climate change (see Chapter 2.7). Oscillations in the lower part of the Baltoro glacier, back and forth by a couple of hundred meters, are now and will probably also be in future due to a reaction of the tributary glaciers to changes in climate, as these glaciers present much smaller accumulation areas at considerably lower elevations (Mayer et al. 2006).

Baltoro glacier was used by Mihalcea et al. (2006, 2008) to demonstrate the relationship between ice ablation with debris thermal properties and meteorological conditions. Their results could be used to estimate melt water production of glaciers.
Smiraglia et al. (2007) and Diolaiuti et al. (2003) reported terminus changes in nearby Liligo glacier. The glacier with a length of roughly 15km and a surface area of $17km^2$ was said to be advancing until 1909 when a strong retreat started, lasting until 1985. Diolaiuti et al. (2003) reported of a retreat by around 1300m between 1929 and 1954 and an advance of 350m between 1954 and 1986. From 1986 to 1997 they identified a surge type increase (see Chapter 2.7) followed by a strong retreat and the formation of a ice contact lake (Smiraglia et al. 2007).
Haritashya et al. (2007) identified the glacier terminus change of different glaciers comparing remote sensing images from the Baltura/Hispar region and Baltoro region for the period from 1973 to 2004 and 1979 to 2003, respectively. Results summarized in table 5 indicate an advancing or similar terminus position for 45% of the studied glaciers. Especially the small to medium sized glaciers show retreating tendencies.

Glacier lakes

A glacial lake is defined as water mass existing in a sufficient amount and extending with a free surface in, under, beside, and/or in front of a glacier and originating from

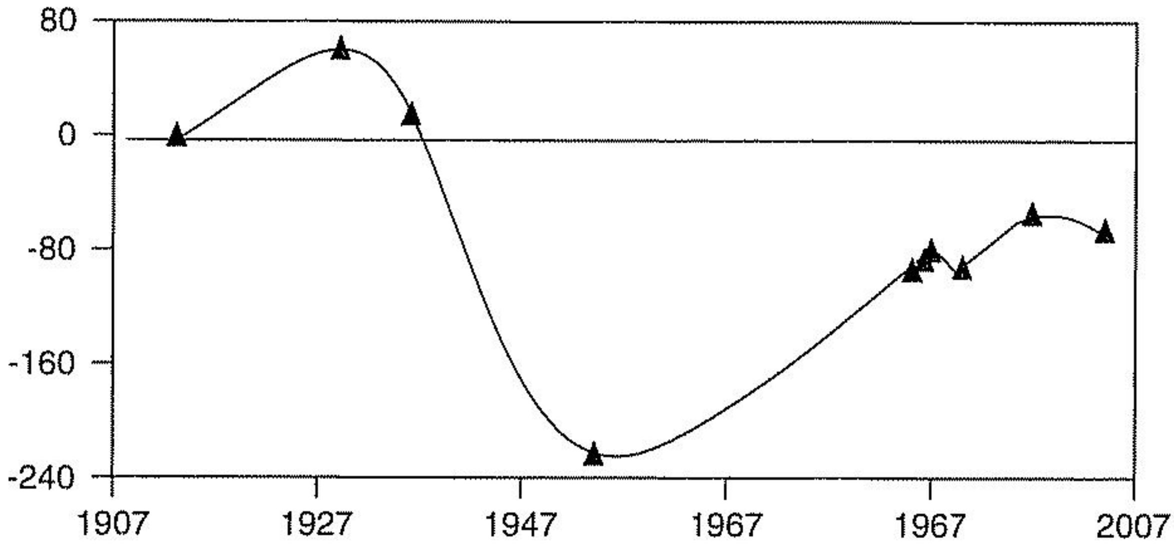

Figure 15: *Baltoro Glacier terminus showed only minor fluctuations between 1913 and 2004 in comparison with its total length of 62km. X-achses illustreates the derivation from the snout position of 1913 in m.*

glacier activities and/or retreating processes of a glacier. The lakes are classified into Erosion, Valley trough, Cirque, Blocked, Moraine Dammed (Lateral Moraine and End Moraine Dammed lakes), and Supraglacial lakes (Campbell 2004).
The lakes located at the snout of the glacier are mainly dammed by the lateral or end moraine, where there is high tendency of breaching. Rapid accumulation of water in these glacial lakes, particularly in those adjacent to receding glaciers, can lead to a sudden breach of their unstable moraine "dams". The resultant discharge of huge amounts of water and debris "a Glacial Lake Outburst Flood" (GLOF) often has catastrophic effects downstream and causes serous damage to human life and property (Campbell 2004). Prominent examples from the Northern Areas were the Shimshal flood from Khordopin glacier and the Karumbar flood in 1905 from Karumbar Glacier.
Campbell (2004) compiled an inventory of glaciers, glacial lakes and identified the potential for glacial lake outburst in different regions in Asia including Pakistan. In this three years project they identified and mapped 5218 glaciers with the glacier area covering around 15040 km^2 and 2420 lakes in Pakistan by using remote sensing techniques (Table 6). Among the identified lakes 52 lakes were classified as being a potential threat of glacial lake outburst floods. The aim of the study was to assess the threat from glacial lakes and to highlight those where glacial outburst flood events are likely to occur and cause serous damage to human life and property. Unfortunately the internet resources provided to share the output of this 200,000 $ project with possible planers and users is not any more accesable via internet. Dr. Rakhshan Roohi (Water Resource Research Institute, National Agriculture Research Center, Islamabad) was so kind to share the data which can be assesed from the WWF Islamabad or the authors.

Table 5: *Smiraglia et al. (2007) used remote sensing images to compare the glacier terminus change for the the Baltura/Hispar region (a) and Baltoro region (b) for the period of 1973 to 2004 and 1979 to 2003, respectifely. 45% of the studied glaciers showed increasing or stable glacier terminus.*

a) Baltura region			
Glacier	Rate (meter/year)	Glacier	Rate (meter/year)
Barqu	-2.4	Hispar	-7.7
Batura	-13.8	Karun E	-5.5
Bualtar	-5.8	Karun SW	+7.1
Ghulkin	+5.7	Karun N	-5.9
Ghutulji	-5.1	Lupghar Yaz	-2.9
Gorambar	+12.8	Momhil	+10.2
Gujerab N	+6.8	Passu	-9.7
Gurmit	-10.2	Silking	-4.4
Gurpi	+18.4	Silking NE	-4.9
Gutumi	-6.8	Yengutz Har	+7.6
b) Baltoro region			
Glacier	Rate (meter/year)	Glacier	Rate (meter/year)
Baltoro	-2.7	Liligo E	-2.9
Biafo	-16.3	Liligo W	-24.0
Borum	+17.7	Lungka	+4.4
Ching Kang W	+8.6	Lungka W	+4.7
Chorico N	+18.6	Nang Brok	-2.5
Chorico S	-1.2	Paiyu	+10.0
Double Peak	+5.2	Panmah	-6.0
Feriole	-135.1	Shing Chukpi	+80.4
Hurlang Lungma	+5.5	Small Mango	-2.7
Liligo	+77.8	Stokpa Lungma	+1.9

Glacier surges

"Glacier surges are relatively short-lived episodes involving a sudden increase in ice movement by at least one order of magnitude, sometimes two orders, compared to pre-surge, and post-surge behavior" (Meier & Post 1969, Kamb et al. 1985 in Hewitt 1998). This is probably achieved mainly by rapid sliding at the bed (Hewitt 1998) which could be influenced by internal, mainly thermal, hydrological developments (Fowler et al. 2001 in Hewitt 2007). Generally surges are isolated developments of single glaciers (Sharp 1988, Murray et al. 1998, Hewitt 2007).
Surges are a threat to livelihood, as they can generate sudden floods, engorge occupied land and disrupt pathways to local communities below and across glaciers (Hewitt 1998). This has for example happened at Hispar, were the regular path up to Hispar Pass was cut off. The pastures along the ablation valley beside Hispar Glacier upstream

Table 6: *Summary of glaciers, glacial lakes and potentially dangerous glacial lakes of the studied areas by Campbell (2004) in Northern Pakistan.*

River Basins	Nr.	Area	Ice Reserve	Nr.	Area	Dangerous
Swat	233	223.55	12.22	255	15.86	2
Chitral	542	1903.67	258.82	187	9.36	1
Gilgit	585	968.1	83.35	614	39.17	8
Hunza	1050	4677.34	808.79	110	3.21	1
Shigar	194	2240.08	581.27	54	1.09	0
Shyok	372	3547.84	891.8	66	2.68	6
Indus	1098	688	46.38	574	26.06	15
Shingo	172	36.91	1.01	238	11.59	5
Astor	588	607.03	47.93	126	5.52	9
Jhelum	384	148.18	6.94	196	11.78	5
Total	5218	15040.7	2738.51	2420	126.35	52

of Pumarikish Glacier were not accessible, and the Hispar yaks were mostly refined to grazing at Bitanmal (Searle & Wake 1993). Especially glacial outburst floods generated by surging tributary glaciers blocking main unglaciated valleys have caused extreme floods in the past (Archer 2002).
Surges tend to recur in cycles peculiar to each glacier involved and out of phase with general patterns of glacier advance and retreat. Surges complicate the normally rather sensitive relations between glaciers and climate (Hewitt 1998).
There are reports of 34 surges in the Karakoram since the 1860s involving 23 glaciers (Hewitt 1969, 1998, 2005, 2007). Twelve of these are tributaries of main glaciers that are not known to surge. Since 1985 thirteen surges have been recorded in the Karakoram more than in any comparable period in records since the 1850s (Mason 1930, Hewitt 1969, 2007). Diolaiuti et al. (2003) and Smiraglia et al. (2007) identified surge type behavior for Liligo glacier. Four tributaries of Panmah Glacier have surged in less than a decade, three in quick succession between 2001 and 2005. An overview over glacier changes from 1997 to 2001 demonstrating the high number of surging glaciers is provided in table 7 published in Hewitt (2005).
Hewitt (2007) points out that until 2000 glacial surges in Northern Area seemed temporally and spatially unrelated. However, the events between 2001 and 2005 taking place at Panmah Glacier were temporally synchronous even as three glaciers were not related to the main glacier. Hewitt (2007) suggests climate change as the only explanation for "coordinated" surges at Panmah Glacier.
There is growing evidence that climate can influence surges. It may occur through mass balance change, through episodes of exceptional ablation and free water ponding, and through ice thermal change (Hewitt 2007). Surge intervals have been shown to reflect the net rate of accumulation over intervening periods at Variegated Glacier, Alaska, and at Edvezhiy Glacier, 450km northwest of Panah Glacier (Eisen et al. 2001).

However, Hewitt (2007) does not believe that mass balance changes alone could initiate surges in glaciers being inactive over decades. He suggests that a critical threshold had been reached. Temperature change could heat up frozen cold ice. The resulting wet conditions can dramatically affect glacial movement. The observed increase in summer and winter precipitation (Fowler & Archer 2004, 2006, and own results) as well as winter warming but summer cooling attributed to greater summer cloudiness and storms (Fowler & Archer 2004, new results) detected in the valley stations would favor positive mass balances (Hewitt 2007). However, Hewitt (2007) questions the comparability of climatic date recorded in valley stations below 3000m with the behavior of high altitude glaciers.
More high altitude records as well as more specific long term studies would be needed to come up with definite answers on the influence of climate change on glacial surges. Northern Areas provides the ideal conditions for such detailed research.

2.8 Concluding discussion on glacier changes

Nearly all over the globe glaciers are showing retreating tendencies as a result of global warming. Depending on the size of the glacier and its catchment area the actual glacier extend lags behind climate change by anywhere between a few years up to many centuries (Lemke et al. 2007). Even if the majority of glaciers in the Karakoram mountains are retreating, a large number especially of large high altitude glaciers shows static or increasing behavior (Hewitt 2005 and Haritashya et al. 2007). This contrast in the behavior of glaciers suggests a pattern of climate change in the Karakoram different from that of the Himalayas (Fowler & Archer 2004).
Smiraglia et al. (2007) argues that especially debris covered glaciers in the Karakoram are responsible for the different behavior, as the debris prevents the ice from fast down melt by temperature increase in the ablation zone. As high altitude precipitation is the main source for glacier mass balance a change here would cause major changes. Proper information according to snowfall changes in adequate spatial resolution would enable much better identification of mechanisms and allow conclusions and maybe even predictions.

3 Impacts of climate change on the Northern Area

3.1 Hydrology

The Indus Basin Irrigation System (IBIS) relies heavily on the runoff generated by melting of snow and ice in the Upper Indus Basin. Khan (2001) claims that the irrigation canals of IBIS withdraw almost 75 % of the mean annual runoff available in all the major rivers of the Indus Basin . Hydropower also provides 28% of the installed power capacity of the country most importantly from the two large dams at Tarbela on the Indus and Mangla on the River Jhelum (Archer 2003). The planned construction of future dams on the indus river will increase this figure in the coming years and will so increase Pakistans dependency on a guarantied annual inflow into the reservoirs to meet the rising power demand.

River flow

The input into the IBIS can roughly be divided into two mayor components, distinquished by the elevation range. Snowmelt in summer can only occur in that portion of the catchment, that is "above the snow line and below the freezing level" (Archer (2003)). The lower the catchment is in elevation the higher the proportion of precipitation that falls as rain and directly enters the river system after only a short lag. High altitude catchments like Shyok and Hunza momentarily have 60% of annual runoff in July and August. A time when also the planted vegetation needs a lot of water. Due to climate change, the snowline in these high altitude catchments may change, resulting in a higher direct runoff in winter and a decreese of water level in summer, when it might be needed for irrigation. So although the same annual amount of water is in the system, the usability of the water might decrease in future. It is possible, that part of this shift can be compensated with the earlier planting season, that might be possible in a warmer climate. According to Archer (2003) the glaciers and permanent snowfields provide a longterm storage for precipitation, buffering the variability of annual precipitation and providing a constant input to the IBIS. If some glaciers are strongly decreased, they can no longer provide the river system with the same buffering capacity, allowing drought years to have a stronger direct influence on water levels and thus irrigation.

The runoff from different altitude catchments is predominately dominated by different drivers (Archer 2003). These consist of:

High altitude Karakoram catchments with large glacierised proportion (Hunza, Shigar and Shyok) have summer and annual runoff that is strongly dependent on concurrent energy input represented by seasonal temperature.

Middle altitude catchments (Astore, Kunhar and Swat) have summer flow predominantly defined by preceding winter precipitation. However, the Gilgit and the Indus above the Shyok confluence also show the same winter precipitation control.

Foothill catchments (Khan Khwar and Siran) have a runoff regime that is controlled mainly by liquid precipitation, predominantly in winter but also during the monsoon.

Floods

The high ablation rates of glaciers in summer cause the IBIS to be prone to flooding and strong erosion. According to Archer (2002) there are four distinctive ways floods are generated in the Karakoram:

Melting of snow and glacier ice occurs annualy and result in the highest flow of the year.

Monsoon rainfall falls predominantly in July to September in the foothills of the Himalaya and Karakoram. Suprisingly in the northern valleys runoff decreases during monsoon precipitation events, as cloudy skies reduce glacier ablation.

Dambreaks following landslides into rivers The high relief energy eminent in the Karakoram valleys can cause mayor landslides to occure, blocking the bottom of whole valleys and generating natural dams. These dams will stow the river into a lake until the pressure of the water breaks the lake and releases the water.

Outburst of glacial lakes occur on and around glaciers and are mostly held back by glacier moraines that often contain an unstable ice core prone to subsidance and melting, causing the moraine to suddenly give way to the water masses. In the Karakoram glaciers are known to surge sudenly, blocking the whole valley and causing a stowage of the river. Such is e.g. reported from the Karamber valley in 1905

While the first two kinds of floods happen on a regular yearly basis with little variation, marking the yearly maximum, the later two kinds of floods are a lot less frequent, but can be of a greater magnitude causing immense damage (Archer 2002). Due to climate change it is possible, that the summer runoff from melting of snow and ice increases, resulting in stronger yearly floods with more potential for erosion and destruction. On the other hand climate change may lead to a change in seasonality rather than an increase in magnitude. Archer (2001) postulates, that an increase of winter temperature might shift the altitudinal limit between winter rain and snow upwards, thus decreasing the amount of snow available for melting in summer, reducing the maximum summer flood level. Archer (2001) furthermore states that climate change might alter precipitation patterns resulting in more torrential rain and thus increasing the chance of triggering a landslide. But bear in mind, all the aforementioned scenarios, are only speculation by Archer (2001), without any scientific findings to back them. Ali (2008) states that the analysis done by the Global Change Impact Study Centre in Islamabad have revealed a slight overall decrease in annual runoff in all mayor river systems fed by glaciers. This could either lend credibility to an overall increase in glacier masses or be caused by an decrease in annual precipitation.

3.2 Livelihood

No scientific research could be found dealing explicitly with the effects of climate change on livelihood in Northern Areas Pakistan. This might have different reasons, not availability of high resolution meteorological data being only one among others.
To evaluate the villagers own perspective a questionnaire was conducted in four different communities throughout the Northern Areas. The communities questioned are Passu, Shimshal, Hisper and Karamber Valley. All are associated to one or more glaciers and are largely dependent on glacier outflow. The results of the survey are summarized in the following. For detailed outcome and the questionnaire itself refer to appendix A.

Summary of the questionnaire

An increase in summer and winter day and night temperature was reported for all villages. In many cases this caused a change in the growing season. As most villages plant after a traditional date, the change is mostly towards an earlier harvest time. However, agriculture is strongly affected by the substitution of traditional crops like barley and black and green peas to cash crops like potatoes. Yields seem to be largely dependent on the availability of manure from livestock. A decrease in per capita livestock has a negative effect on the yield. Industrial fertilizers can often not be afforded in adequate amount or is suspected to deplete the soils after a few years. The decrease is also caused by the migration of people into cities and a shift in the main source of income to other activities. Hisper was the only village where an increase in yield was reported. Probably due to differences in religion and connectivity, education in Hisper is low in comparison to the other villages and urban migration does not take place to the same extend. The improvement of water and medical facilities decreased (child) mortality and thus population and livestock are said to be increasing.
All villages reported less snowfall in winter and mostly also less rainfall in summer. Reports of changes in the main wind direction in Shimshal might indicate a change in general atmospheric patterns. Landslides as well as (glacier outburst) floods are a major problem in different communities, depending on their spatial situation. However, reports about extreme events have not been consistent. This is probably due to difficulties remembering and evaluating such rare events.
Reports concerning glacier extend have been found to be roughly consistent with scientific findings. Villagers could not really deal with our questions concerning ecology. Especially wild plant species do not get much awareness. These seem to be strongly affected by grazing and wood harvest. Animal species are mainly suffering from illegal hunting and maybe habitat fragmentation and destruction.
Major improvement wishes of the communities varied according to location from education (more schools, higher education), health (need of health care center), flood and landslide protection, market access, cheap fertilizers and employment to generate money.

Discussion on the effects of climate change on livelihood

Rural communities experience major changes. Improved education and marked access lead to urban migration, shifts in main income sources and changed life style. Agriculture looses its importance. Sometimes livestock was even only kept out of tradition (Sanan 2008). Altogether it seems that according to local population cultural and economical changes exceeded changes in climate change by far.
However, on the long run, expected future climate change might have a severe influence on culture and lifestyle in the Northern Areas. As ancient cultural habits and traditions are often directly linked to environmental settings. A change in mean temperate of roughly 4 °C by 2080, as predicted by the downscaling of GCMs (see 2.5), would raise the average temperature in Gilgit nearly to Islamabad level. Even more severe might be a change in precipitation pattern, as the Karakoram ecosystems seem to be more limited by water than temperature.
Climate change in Northern Areas might therefore bring benefits for agriculture and income in rural communities on the short run. However, together with the ongoing external influence it will cause the loss of culture and tradition in a region, whose cultural and linguistic diversity is outstanding and famous on a global scale.

3.3 Ecosystems

Mountain areas are said to play a key role for investigations on the effect of climate change on ecosystems in general and floristic patterns in special. Due to the altitudinal gradient certain processes respond very specific to changes in the climate (Eberhardt 2004 p.13). Eberhardt (2004) also points out, that the relief in the Karakoram implies a very strong vegetation gradient. Mesoclimatic effects however can overlay overall vegetation patterns.
Dickore & Miehe (2001) comprises the flora of the Karakoram as a "Cold Spot" of biodiversity. Due to the desert like precipitation in the valleys and the all encompassing glacier extend during the last ice age the overall species number found in the Karakoram is considered as low. But "zones of particular interest and vulnerability do not necessarily mirror diversity hot spots" as Dickore & Miehe (2001) stresses. A considerable number of species from the mountain flora is listed in the first "red list" of vascular plants for Pakistan (Chaudhri & Queshi (1991)).

Ecosystems and land use

The flora and fauna in Northern Areas Pakistan suffers immense pressure from land use. For fauna recent conservation efforts seem to have improved the situation. A wildlife survey conducted by IUCN (2004) suggests that wildlife population has increased over the last years. However Nyborg (2005) points out that wildlife population surveys in the area are difficult because of the difficult terrain and migratory nature of wild animals. The increase in wildlife population could therefore also be a result of double counting.

In many parts of the Northern Areas organized trophy hunting was introduced. As the majority of the earned money goes to the local communities their awareness and active participation in wildlife conservation has increased. However illegal hunting remains a big problem, especially in these areas were no organized trophy hunting takes place. Further on there are indications that high government officials misuse national parks (like Khunjerab National Park) as private hunting areas without involvement of local actors or communities (Source wants to remain unknown).
Overgrazing seems to be the major threats to vegetation in Northern Area Pakistan. At least for the upper Hunza valley Eberhardt (2004 p.160) disputes the findings of Kreutzmann (2000) that livestock is in general decline. He finds the herds per household to remain stable with an overall increasing household number. He observes and predicts a change in land usage pattern resulting from the shortage in manpower. The usage of high pastures is in decline with the grazing activity now concentrating on the near settlement surroundings. This will on the one hand enable vegetation to recover in the former high pastures. On the other hand the valleys will suffer from enormous degradation. Eberhardt 2004 claims the grazing activity to be already near or over maximum sustainable carrying capacity.
The demand for timber and firewood has increased, not only due to increased population (Nyborg 2005). The rate of deforestation is estimated to be about 30% during the last three decades. It has especially increased due to higher demand from down country and improved road access to forest covered areas. Responsible for the majority of clear cutting was commercial harvesting, mismanagement by the government and a "timber mafia" mainly during the 1970s and 1980s (Ali & Benjaminsen 2004). *Juniperus* trees older than 2000 years are radically cleared (Esper 2000, Eberhardt 2004). According to Ali & Benjaminsen (2004) the forest has been left in a condition that is not able to meet the needs of the local population.

Ecosystems and climate change

Because of different topographical and climatic settings, one can not easily transfer findings concerning the effects of climate change on ecosystems from other parts of the world to the Northern Areas. However it could be suspected, that an increase in temperature will be followed by an upward shift in species as observed in the European alps (Walther et al. 2002). Probably this vegetation shift will lag behind the shift in temperature following the humid-adiabatic temperature gradient of 0.6K per 100m altitude. As plant species need a certain time to shift their habitat, it is suspected that some species might not have the dispersal abilities to keep up with the speed of temperature change. Further on a shift in species composition might take place and species might not find suitable habitats on the elevation suitable to their future climatic needs. This might especially be true for species that slowly influence the environmental settings like soil quality or acidity to their needs. However the Karakoram Mountains are considered as a high altitude desert. Therefore precipitation changes should have an even more severe effect than changes in temperature.
Future projections can not be done, as at present little scientific research have been

carried out and published addressing the effects of climate change on ecosystems in the Northern Areas Pakistan. However a basis has been laid by ecological studies like the taxonomic mapping of the vegetation of the upper Hunza by Eberhardt (2004), the Naltar valley by Sheikh et al. (2002) and the Nanga Parbat region by Wolf Bernhard Dickore (2000). But as Dickore & Miehe (2001) lays out "taxonomy is doubtful and requires further international efforts in biosystematic research". Taxonomy can only be the starting point for research and monitoring of climatic effects on ecosystems in the Northern Areas. Here people rely on natural resources and culture is tightly connected to environmental setting. Knowledge about a possible future change in ecosystems is therefore highly valuable. Tight economic but also cultural connections to the lowlands make a change in Northern Areas Ecosystem a nationwide issue. Information gained in this extreme environment can become highly valuable for international climate change research.

4 Personal conclusions and recomendations

The Northern Areas of Pakistan - similar to the rest of the world- are affected by climate change. But the Northern Areas are a quite special place, with unique topographic, environmental and cultural setting, but also with a variety of specific problems and future challenges.
New socioeconomic influences like the establishment of the Karakoram Highway have brought large changes to the Northern Areas. On the one hand the improved accessibility provided larger personal and economic flexibility. It introduced external influences like institutions, tourism and trade. It also simplified the work of government and non government organizations and with that improved community institutions like education, health, water and electric facilities. On the other hand modern influences brought changes to various fields ranging from lifestyle over agricultural practices and other land use matters like forest utilization to new house construction techniques. All these changes might improve living conditions, but will also ultimately lead to the loss of culture, knowledge, community structure, scenery and ecological values.
Up to now these socioeconomic change by far outweigh any climatic changes. Climatic changes have so far remained in or at least near margins of natural fluctuations and might therefore still lie within the corridor of adaptability for people, culture and ecosystems. Future climate alterations will most likely exceed historic fluctuations and therefore push the environmental setting into an unknown direction.

Scientific research in the Northern Areas has a long tradition and many different agents are working in this area. However we found this research in parts uncoordinated. Information accessibility and exchange being one of the larger problems, especially within Pakistan. While working, we had the ability to visit many institutions and people, mostly from Pakistan, working on the topic of climate change. And we had the feeling that nowadays communication is improving rapidly. Above all the establishment of the Karakoram International University as a central institution for Northern Areas research activities will - when finalized - enable much easier centralized access to various information and will therefore catalyze research activities and cooperations. In this paper we tried to cover all recent research done on the effects of climate change on glaciers, ecosystems and livelihood in the Northern Areas. We hope, that it will be used as a starting point for future research and action in this very present field.
The missing publication of meteorological data especially for high altitudes in Northern Areas is a big problem in identifying the relationship between changing climate and glaciers. These Data are hosted with WAPDA or the Bonn University, while meteorological Data for the valleys is collected by the Department of Meteorology. We would suggest better data management in Pakistan. The call is for one central institution that collects and shares the data of all involved parties, similar to e.g. the Chinese system.
The effect of climate change on the hydrological cycle, in Northern Areas mainly over glaciers, is investigated by many different institutions like the Global Change Impact Studies Centre, the Water and Power Development Authority, the Water Resources Research Institute (NARC), the Meteorological Department Pakistan, as well as many

foreign researchers and research groups. Many questions remain in this field especially concerning volume changes and mass balances of glaciers. Some efforts have to be done on the exchange of publications, as international once are often not accessible from Pakistan, while Pakistani institutes tend to be slow in publicizing their findings internationaly.

Assessing the combined effect of social and climate changes is a major task for the future. The largest gap in knowledge concerning climate change effects remains with ecosystems. Effects by the changes like the altitudinal temperature gradient, precipitation patterns on ecosystems and ecosystem services can only be suspected. The interference between land use changes and climatic changes remains uncertain. With the Karakoram being a very good research area for the relation between climate change and ecosystems, we suggest much more national and international research on this field. We also would suggest a second report like the current one, dealing explicitly with this subject.

Research is only the first step towards action. However we found past climate change to be of benefit for livelihood in Northern Areas, with large uncertainties for the future. But rural communities still have to cope with large problems and the ongoing efforts have to be strengthened. With ecosystems being the basis for economic and cultural activity and with finding them besides climatic changes under threat by overuse like timber extraction, overgrazing, construction activities and other activities we advice more intense efforts in this field. Nature conservation is not only (but also) establishing large national parks in remote areas, it means enabling life of local population in a sustainable relation with the surrounding environment.

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A appendix

Questionnaire concerning climate change affecting livelihood

To evaluate the communities own perspective on recent environmental changes, we filled a questionnaire in four different communities throughout the Northern Areas. The communities were Passu, Shimshal, Hisper and Karamber valley. All are associated with one or more glaciers and are mostly dependent on glacial outflow.
To avoid answers tailored to what villagers perceived as the questionnaires expectations, typical climate change key fraises were avoided as much as possible. This was done, because everybody might have heard about climate change and associates it with increasing temperature. People might also want to indicate their need for financial support by answering in a specific way. The questioning was therefore conducted in a way that the people should not notice the interest in climate change and associated phenomena.
The focus was on elder people, always living and working in the village age to cover a relatively long time span. All questioned people were male, as they were much easier accessible for us. Translation to/from local dialects was kindly conducted by Rashid Sanan for Passu and Hisper, Raja Abid for Karamber and by two unknown, but very kind mountain guides in Shimshal.

The questionnaire was the following in this order:

1. What kind of crops do you grow or are grown in the region? (once per village)
2. Do you now plant other crops than you have been growing in earlier times? Since when and why?
3. Did crop yields change in the last five years in comparison to the time before and why?
4. Has the growing season increased in the last five years in comparison to the time before? Did you plant later or earlier in the last five years than previously? What about harvest time?
5. Do you do double cropping in place of single cropping now or in the past?
6. Can crops now be grown in higher places, where they could not be grown before? How much higher? Why?
7. Was there any change in the date of the last/first frost over the last five years?
8. Is there any change in the volume of the stream flow from the glacier? If yes, it is higher or lower?
9. Are there more floods in the last years in comparison to your childhood? Are these a problem?? What can one do against them?

10. Was there any change in the size of nearby glaciers over the last twenty years? (Extend and speed). Have you heard of abrupt increase in glacier size? Do you have cyclic retreating and growing glaciers in the area?

11. Does the snow cover stay longer on the ground in the last five years than previously? Has there been more snowfall in winter? Are there now more avalanches than previously?

12. Has there been more rainfall in summer previously?

13. Did you realize a change in the main wind direction?

14. Which are the important plant and wildlife species in your area? Are there new species of plants and animals in your area that have not been here before? Have species of plants and animals disappeared in the last five to ten years? Which? What could one do against the decline of wildlife species?

15. Do migratory birds come earlier than they used to?

16. Are there more droughts or storms in the last years in comparison to your childhood? Are they a problem? What can one against them?

17. Are there more land slides in the last years in comparison to your childhood? Are they a problem? What can one against them?

18. Is there a change in night/day temperature in winter over the last five years?

19. Is there a change in night/day temperature in summer over the last five years?

20. Which of the Glaciers is male/female? Can there be a change in the gender?

21. What do you see as the major problems of your community? What challenges of the future can you not face alone?

22. Do you have questions?

The summary of the results is structured according to topics and does therefore not follow the same order as the asked questions. Terms like "in former times" or "previously" always refers to the youth of the questioned people. The presented contend reflects the opinion of the local people and is not necessarily consistent with scientific findings. A short summary of the results can be found in chapter 3.2.

Passu

In Passu all questionnaires were conducted in the private homes of the people. This enabled an undisturbed questioning in privacy. The average age of the men was 70.

Temperature An increase in summer and winter day and night temperature was reported for Passu. While some said the frost period had not changed others believed it to be shorter now and spring melting to start earlier now. It was told that in former times sometimes there had still been snow besides the fields when ploughing started in April.

Precipitation All agreed that there is now overall less rain and snowfall. In former times snow cover stayed up to six month. This year no snow fell at all.

Natural hazards Strong winds in winter were reported to have always caused damages. There was a strong discrepancy in the statements concerning changes in storm occurrence. No changes in main wind direction have been observed.
In 1992 strong rainfall events have been reported to cause the death of ten people.
Landslides are not a problem in Passu, as there is no houses construction in high risk areas.
It was reported that a glacier outburst flood of Passu Glacier took place on January the 6th 2008. Statements about occurrence frequency varied from all three years to three times in the life of the questioned man. Normally these floods take place in summer, but this year they seem to have come from a GLOF
Much bigger floods caused from breaking glacial lakes further upstream the main river had caused major damages in the past. Especially the outburst of Shimshal glacier was reported to be very severe. Large parts of the village have been washed away at that time.

Glaciers The volume of the stream flow from the glacier has increased.
The glacier with major importance for water supply is Passu glacier uphill from the village (few kilometers). It was reported that it had been further down near a Hotel at the KKH in the time of their forefathers and has been retreating for kilometers over the years. If it is currently increasing or decreasing was not clear among the answers.

Baltura glacier seems to be outside the scope of vision for most people from Passu. No clear statements could be derived. Some said it varies over the years, other claimed it to be retreating. An old tale reported of a pasture at the place of the glacier. A bad Chinese fellow, who was even said to open the Quran (The Holy book of Muslims) from the wrong direction, performed evil magic and created the glacier.

The concept of male and female glaciers is not very prominent in Passu, most people did not know the gender of the glaciers. Baltura glacier is said to be either male or a combination of a pushing male glacier and a female glacier creeping over the males back. Overall female glaciers are said to be static, while male once are said to be varying in size over time.

Agriculture Barley, black and green peas lost in importance, as wheat and especially potatoes are now mostly grown as cash crops in Passu. It was stated that the older crops had been healthier.
Yields have decreased over the years. The reason given was an overall change in lifestyle. More and more people from Passu are now working mainly in other sectors. A decline of livestock decreased the availability of manure. Chemical fertilizer is said to not be as suitable to the soil as it has been at the time of its first introduction. It was also stated that they do not have enough knowledge on the proper use of fertilizer.
Planting now starts later in the year as people are not so dependant on agriculture and as tractors can do the work much faster than oxen. However in spite of the later planting, the harvest time is said to remain the same.
A certain type of double cropping had been done in former time. Barley was harvested when it was still green. After that vegetables had been planted. This is not currently necessary as vegetables are now planted parallel on other fields.
One man said, that some high pastures had been abandoned, as many people now are busy with getting education and jobs outside the village.

Ecology Most men did not notice any changes in species distribution. Two reported the disappearance of a deer species.

Major problems The major problem in Passu was said to be the erosion caused by the floods in the large river. Dams constructed by the government and by Japanese donors have improved the situation but are said to be not enough.

Hisper

The questioning in Hisper was conducted in the one room guesthouse. Therefore it was possible to ask six people in separately. They claimed their ages to range from 55 to 70 years.

Temperature The majority noticed an increase in winter and summer temperature for day and nighttime. Only one man did not feel any differences. There was said to be no change in the time of frost period.

Precipitation Overall rainfall has decreased in Hisper. Summer precipitation events seem to be extreme in intensity. There was no consensus if the intensity has changed and in what direction.
It was reported that snowfall has decreased dramatically. Statements over the amount of change vary. The maximum snow covers in winter decreased from around two feet snow height to roughly one or non as in the year to be.
There was also no consensus about snowfall in the high altitudes (like Golden Peak) but a slight majority opted for increase.

Natural hazards Hisper seems not to have any major wind direction, nor were changes reported. Storms are said to be a problem, as they damage plants. Frequency was said to be 1 to 2 storms per year with no reported changes.
Damages to canal systems and fields were blamed mostly on floods. No changes were reported in their occurrence. Up to now nothing is done to prevent flood damages. However we are not quite sure how the people in Hisper define floods.
Landslide occurrence was reported to decrease together with snowfall. Landslides damage crops, roads and houses.
One man stated that there had been more droughts in former times what ultimately decreased the yields.

Glaciers A slight majority reported that there is now more outflow from the nearby glacier. However some said the opposite or reported of no changes.
Two glaciers are in relative proximity to the village. KAIBAR is situated above (south) of the village and feeds the new constructed sanitation system and the hydropowerplant. BITANMAL is the main valley glacier and might also be referred to as the Hisper Glacier outside the village.
Reports about Kaibar Glacier varied a lot. A report confirmed by three men seems to be the most probable. They reported the glacier had reached the river bed in the time of their forefathers and has subsequently been decreasing up to a point not visible from the village. In recent times it is increasing again and the snout can be seen from the village. The ultimate point of decrease might have been reached ten years ago.
All questioned men from Hisper confirmed that Kaibar is a male glacier.

Most parts of Bitanmal Glacier are debris covered and the identification of its real extend is therefore not trivial. This might explain the variety of answers related to this glacier. Most probably it has been increasing since 25 years.
A story from former times mentioned that the area had been a forest. This is said to be proven by wooden parts that are sometimes transported by the river water.
The glacier is said to be female.

Most men said that only God knows the reason for the gender of glaciers. Two stated that male glaciers vary in thickness, while female glaciers are increasing and decreasing in extend. It was also stated that male glaciers have harder ice.

Agriculture In former times people in Hisper had been growing black peas, green peas, barley and wheat. Later on potatoes were introduced and increased in importance. Now wheat and potato are mainly planted, potatoes being the cash crop. It was stated that fruit trees like apple, apricot, peanut and cherry had been introduced 30 years ago while it was reported that they had been introduced into the nearby Nagar some 300 years ago. It is interesting that Hisper does not seem to have a tradition of tree plantations for firewood like in many other communities, instead villagers walk up to four hours to collect wood.
Hisper has an increase in yields, as the livestock has increased and there are more villagers to tend the herds and collect the manure.
The majority reported that planting season starts at the same time. Only one man said it might now be ten days earlier. Harvest is up to 20 days earlier. However, there is no possibility to do double cropping,

Ecology No new species were observed in Hisper. Migratory birds like ducks or finches come at the same times of the year

Major problems Major needs of the community are said to be education (more schools, higher education), health (need of health care center), road (marked access), fertilizer, forest planting and employment to generate money.

Karambar Valley

A big group discussion was held in lieu of single questioning, due to time restraint.

Temperature Temperature in Karambar Valley has increased over the years. However, the last winter was reported to have been very cold. No change in the frost period has been observed.

Precipitation Nowadays there is less rainfall. However it is reported to rain in shorter and also stronger bursts, causing major damage. They claimed that more lightning takes place, which they believe is due to the new power lines in the valley attracting lightning. A decline in snowfall was reported for winter season. However the year 2005 had very intense snowfall.

Natural hazards In former times more landslides were observed. These were caused by more snowfall in winter.
Large parts of the villages were washed away by the glacier lake outbursts in the past, but also medium sized floods damage fields. Human death could be prevented in the last big flooding event, as people knew the glacier lake was going to break and left their villages in time. It was reported that a three days flood followed the lake outburst.

Glaciers The volume of the nearby river was static for the period from 1993 to 2003 and started to increase from 2003 onward.
Many glaciers flank Karamber Valley. People could give information on the nearby ones. These were beginning from south: Badswat, Borth, Devjerab, Karamber, Matramdan, Bokh, Piakhin.
Badswat Glacier, near the village, was said to be retreating since 1988. This glacier is reported as male.
Borth Glacier was near the village in 1978. It retreated until 2002 and has now increased by 15 m in length and 10m in altitude.
Dewjerab Glacier has created a small lake. Changes were not under observation. It is said to be male.
Karamber had been blocking the whole valley at the beginning of the 20th century creating a large lake. Its outburst in 1905 caused dramatic damages. Afterwards it retreaed until it reached a position roughly were it is now. It followed a period of sudden increase were it finally reached a position near the road in 1998. Some army specialists monitored the behavior in 1998 and measured an increase of 5 meters within one night. Since 1998 it has retreated a few kilometers up to the current position. Karamber Glacier is said to be female.
There are two glaciers running under the name Matramba Glacier. The one situated at the left handed side (looking from south to north). This one is not moving. The one on the right hand side as well is static, but a lake had been forming and finally burst in 1988. The flood damaged houses and fields. Both glaciers are said to be male.

Bog Glacier was increasing until it reached a position in 1996 and 1997 where it damaged the channels of the nearby village. It has now remained in this position.
For Biachan Glacier no changes were observed. Might be that the later once are already out of observation range of the villagers.
Male glaciers were said to be green, heavy and static, while female once are easy melting moving glaciers.

Agriculture Agriculture changed from wheat, peas, barley and maize to potato as the main planted crop. Yields have decreased as less manure is available for fertilization due to a decline in livestock. No change in the growing season was observed. Double cropping is therefore still not possible. In former times people had been growing more barley in higher altitudes. Now a lot of barley is imported from markets like Gilgit. Now locals use wheat rather than barely because wheat is nowadays easily available from the local market.

Ecology No new species had been observed in Karamber valley. Hunting still seems to pose a problem. It was reported that the area is too large to prevent poaching. Marco Polo sheep *Ovis ammon polii* was sited last time in 1986. No changes in the time of bird migration were observed. Illegal hunting does not occurre along the Karambar glacier because it is included in community controlled hunting areas, where legal hunting permits are issued by Northern Areas Government for Trophy Hunting. However some illegal hunting occurred in the valley which are out side the Community Controlled Hunting Area (away from the Karambar Glacier)

Major problems Land sliding was said to be one of the biggest problems in Karamber valley.

Shimshal

The questioning was held on Sunday 16th of March 2008. As doctors had arrived the whole village was gathered awaiting treatment. The atmosphere therefore was quite good and we were able to interview people privately in our hotel room. The average age of the five elderly people was sixty.

Temperature Winters as well as summers have become warmer and dryer.
All agreed that the frost period has decreased over the years. There were slight differences in defining the temporal extend. Probably the frost period formerly lasted from end of October to March and has decreased to the period of end of November to February. The intensity of freezing in winter must have decreased dramatically, as people stated that in former times they could cross the river over the ice in winter. Nowadays the river is not frozen at all. Also the winter cloth has changed over the years. It was stated that they were much warmer in former times.

Precipitation The last 10 to 15 years have had extremely little snow in winter. And at least the last five to six years have been very warm. Melting definitely starts earlier. This year there was no snow cover at all, while one man stated that in his childhood he had to make paths through the snow to get from one house to the other. The snow was so high that he could hide in these paths. In 1992 an extreme snowfall event took place.

Wind pattern One man noticed a change in wind directions. The wind direction has changed from mainly easterly directions in former times to eastly and westerly winds.

Glaciers There were different answers concerning to changes in the volume of the stream flow from the glaciers. The reason might be that the water is changing over the season and a comparison is difficult. All agreed that the nearby Khurdapin glacier has retreated since roughly 1960 at least 200m and that the thickness of the glacier has decreased. One man stated that his ancestors said that Khurdapin was said to have an 18 years cycle of grow and retreat, that has now stopped. In the 1960 the glacier grew into the valley and blocked the stream, causing a major flood that washed away big parts of the village. Yasgal and Malangudi glacier up the valley have also retreated or at least not changed size.

Agriculture Shimshal community plants wheat, barley, peas, potatoes, cabbage, carrots as well as trees like apricot, cherry and apple. In former times (time of the childhood of the questioned person) there had been only one kind of each cultivated crop and the only cultivated tree had been apricot. People stated, that with the opening of the village new trees (apple, cherry), new seeds for already cultivated species (different quality of wheat and potato) were introduced. There was no clear statement about yield development over the years. Double cropping is not possible in the Shimshal valley. Change in cropping is also influenced by NGOs who deliver advice and support. A change in

altitude of the agricultural land did not take place, as people are bound to the facilities provided by the community. However one man stated that different to now in former times accessibility of the high altitude pastures in the Pamir was limited in winter.
In Shimshal sowing starts in the beginning of April, after a traditional festival. This has not changed over years. However, in former times the crops hardly ripened, as winter came soon and harvesting had to be done by the end of October. Now harvesting is done one month earlier. But winter seems to start one month later.

Ecology No changes in species occurrence or migratory bird abundance was investigated.

Current position of glacier toungues for some visited glaciers

When visiting the communities for questioning we also measured the current location of the glacier tongues. Measurement was done with a GPS (GARMIN GPSmap 60C) kindly provided by the chair of Biogeography of University of Bayreuth.

Hisper glaciers

Two glaciers are situated next to Hisper village.

Kaibar glacier Kaibar glacier is situated above (south) of the village. The new constructed water supply is fed by this glacier. A picture of the glacier tongue can be seen on the cover of this report. The front of the tongue was measured on 03.04.2008, finding it situated at 36,15575 N and 74,98288 E $\pm 10m$ at 3531m altitude.

Bitanmal glacier Bitanmal Glacier might often be also referred to as the Hisper Glacier. The glacier tongue is covered with debris making it difficult to assess if the debris hills bear an ice core and are still connected to the main glacier. On 03.04.2008 a water outflow with open ice was situated at 36,15699 N and 75,02811 E $\pm 5m$ at 3130m altitude (Figure 16 and 17). From here the tongue proceeds forming a hilly, debris covered area, who's edges were following a line formed by the following coordinates: 36,15728 N 75,02814 E $\pm 4m$ at 3127m altitude, 36,15782 N 75,02715 E $\pm 4m$ at 3122m altitude, 36,15840 N 75,02436 E at 3113m altitude, 36,15925 N 75,02345 E at 3102m altitude, 36,16081 N 75,02135 E at 3107m altitude, 36,16202 N 75,02016 E at 3122m altitude, 36,16304 N 75,02038 E at 3085m altitude. For a view looking eastward over the debris covered tongue facing the glacier refer to figure 18.

Passu glacier

Passu glacier is situated south of Passu village. The glacier front can be seen on figure 19 and was situated on 01.04.2008 at 36,45531 N and 74,87843 E at 2562m altitude $\pm 7m$; 36,45568 N and 74,87816 E at 2555m altitude and 36,45575 N and 74,87672 E at 2564 altitude. The end of the white ice on the glacier was measured at 36,45684 N and 74,86975 E at 2728m altitude. The lake situated in front of the glacier can be seen on Figure 20.

Karamber glacier

The tongue of Karamber glacier was visited on 28.03.2008. The frontline is following the coordinates 36,62136 N and 7407919 E at 2881m altitude, 36,62100 N and 74,07925 E at 2880m altitude and 36,62000 N and 74,07830 E at 2872m altitude. Figure 21 and 22 shows the glacier front. According to local guides the glacier had been increased in 1998 up to a position roughly situated at 36,61544 N and 74,06849 E at 2867m altitude.

Figure 16: *Water outflow at Bitanmal Glacier*

Table 7: *Glacier changes observed in the central Karakoram from 1997 to 2001 by Hewitt (2005). Note the high number of surging glaciers.*

Glacier	Length (km)	Elevation (m)	Aspect	Thickening (m)	Terminus advance
SHIMSHAl					
1. Khurdopin	47	7760-3250	N	15-20 (lower glacier)	no
2. Yazghil	31	7852-3200	N	5+ (lower glacier)	yes (into river)
3. Malungutti	23	7885-2900	N	5-10 (lower glacier)	yes (into river)
HUNZA					
4. Passu	25	7610-2550	E	2-5 (mid-glacier)	no
5. Ghulkin	19	7390-2450	E	5-10 (lower glacier)	yes (20 m+)
6. Hispar	62	7885-3000	W	10-20 (upper glacier)	no
7-11. Hispar tributaries			S	varied (lower glacier)	yes
12. Sumalyar	16	7027-3900	NW	10-15 (lower glacier)	yes (Into Miar Glacier)
BRALDU					
13. Tippur	10	6400-2900	NE	10-15 (lower glacier)	yes
14. Biato	66	7290-3150	SE	10-25 (mid-glacier)	no
15.-18. Biafo tributaries			3NE,1SW	varied (lower glacier)	yes
19. Maedan	12	6200-4400	NW	10-40 m (lower glacier)	yes (2.5km 1996-1999)
20. Unnamed	9	6000-4300	SW	lower glacier	yes (1.5km 1996-1999)
21. Baltoro	60	8610-3490	W	?	yes (150m 1990-1997)
HUSHE-KONDUS					
22. Sherpigang	20.5	7740-3520	SW	5-20 (all)	yes (2001)
23-28. Tributaries			3SE, 3NW		yes (2001)
29. Kaberl (Kondus)	26	7665-3300	S	5-10 (upper glacier)	no
30. Charakusa (Hushe)	21	7280-3480	W	10-20 (upper glacier)	no
31. Chupergyatrapsa	3.5	6560-4440	W	10-30 (all)	yes (2001)
32. Ghondoghoro	19	7160-3420	S	10-20 (mid-glacier)	yes (2001)
33. Alling	20.5	6700-3660	SE	5-50 (all)	yes (1997-2001)

Figure 17: *The debris covered snout of Bitanmal Glacier looking from the water outflow westward (position 36,15699 N and 75,02811 E at 3130m altitude).*

Figure 18: *Debris covered glacier tongue at Bitanmal Glacier (often referred as Hisper Glacier). The photographer is facing east.*

Figure 19: *The picture taken from 36,45747 N and 74,88230 E at 2572m altitude shows Passu glacier.*

Figure 20: *A lake is situated in front of Passu Glacier.*

Figure 21: *Karamber Glacier*

Figure 22: *Photograph of Karamber Glacies taken from position 36,62098 N and 74,07754 E at 2906m altitude.*

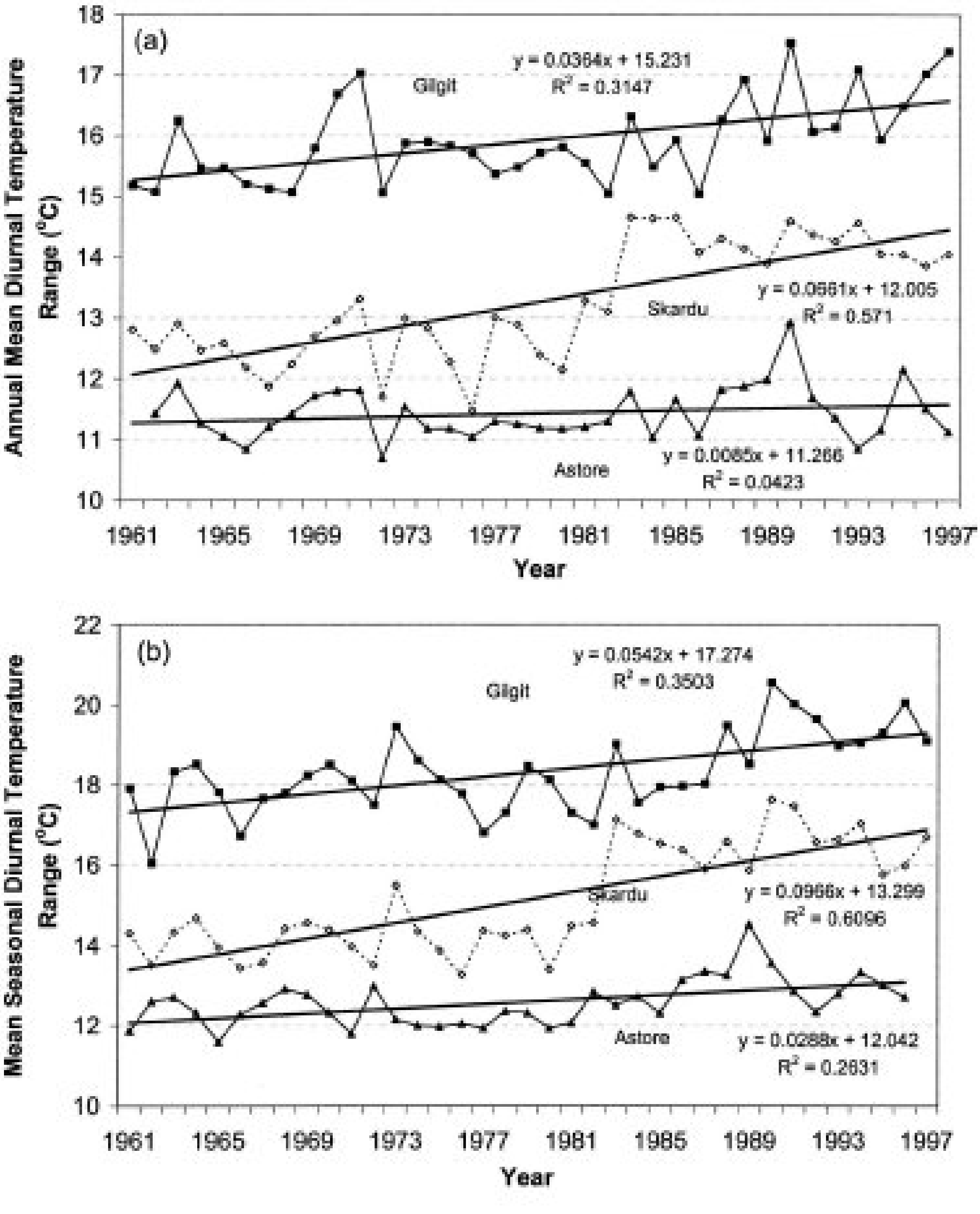

Figure 23: *Trends in diurnal Temperature Range at Gilgit, Skardu and Atore (a) annual and (b) June to November. (Fowler & Archer 2006)*

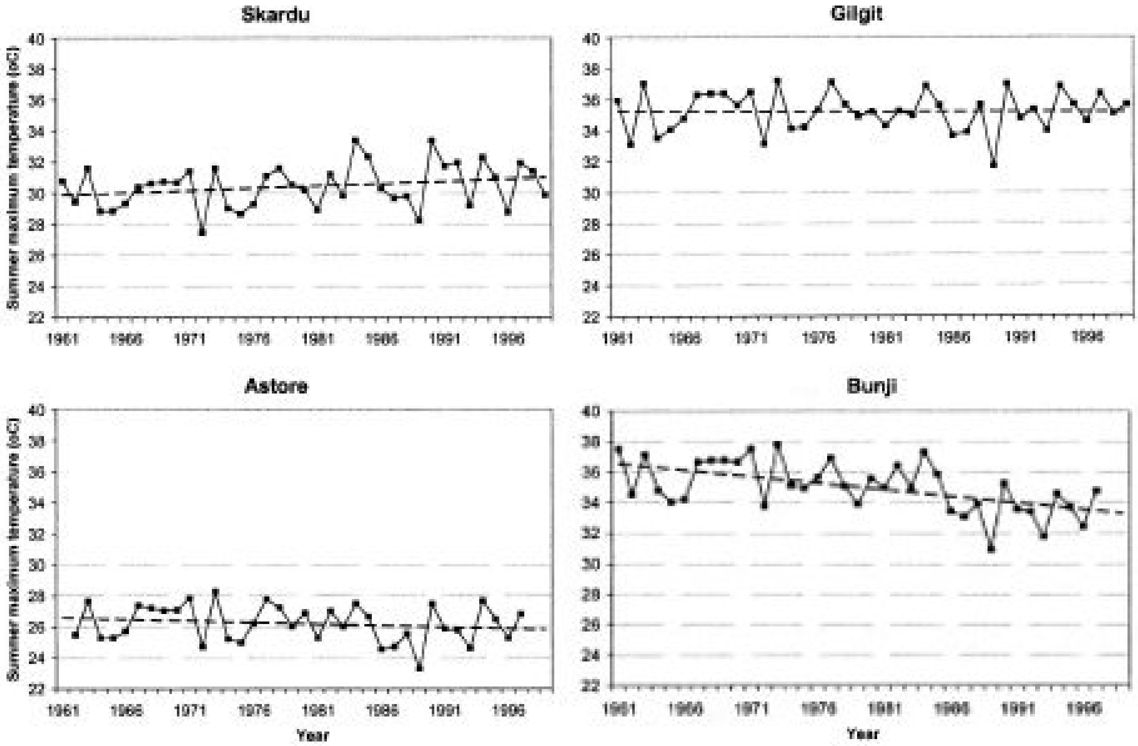

Figure 24: *Trend in summer (JJA) maximum temperature from 1961 to 1999. Panels show temperature time series with fitted linear trend line. (Fowler & Archer 2006)*

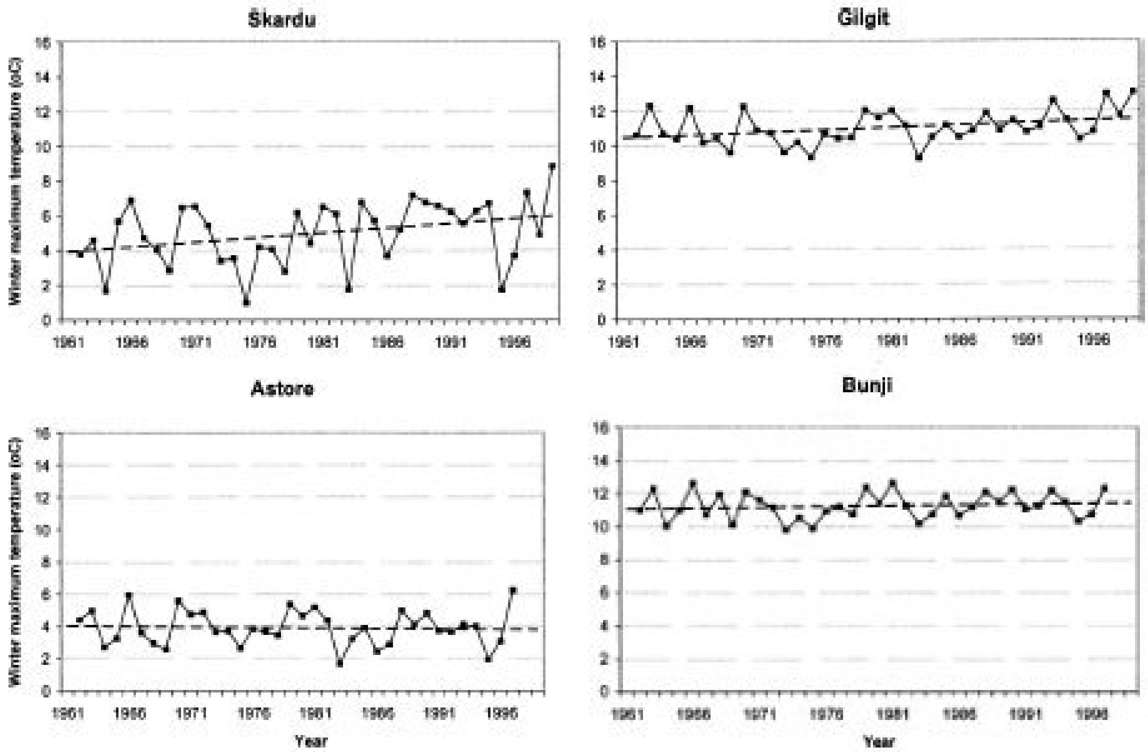

Figure 25: *Trend in winter (DJF) maximum temperature from 1961 to 1999. Panels show temperature time series with fitted linear trend line. (Fowler & Archer 2006)*

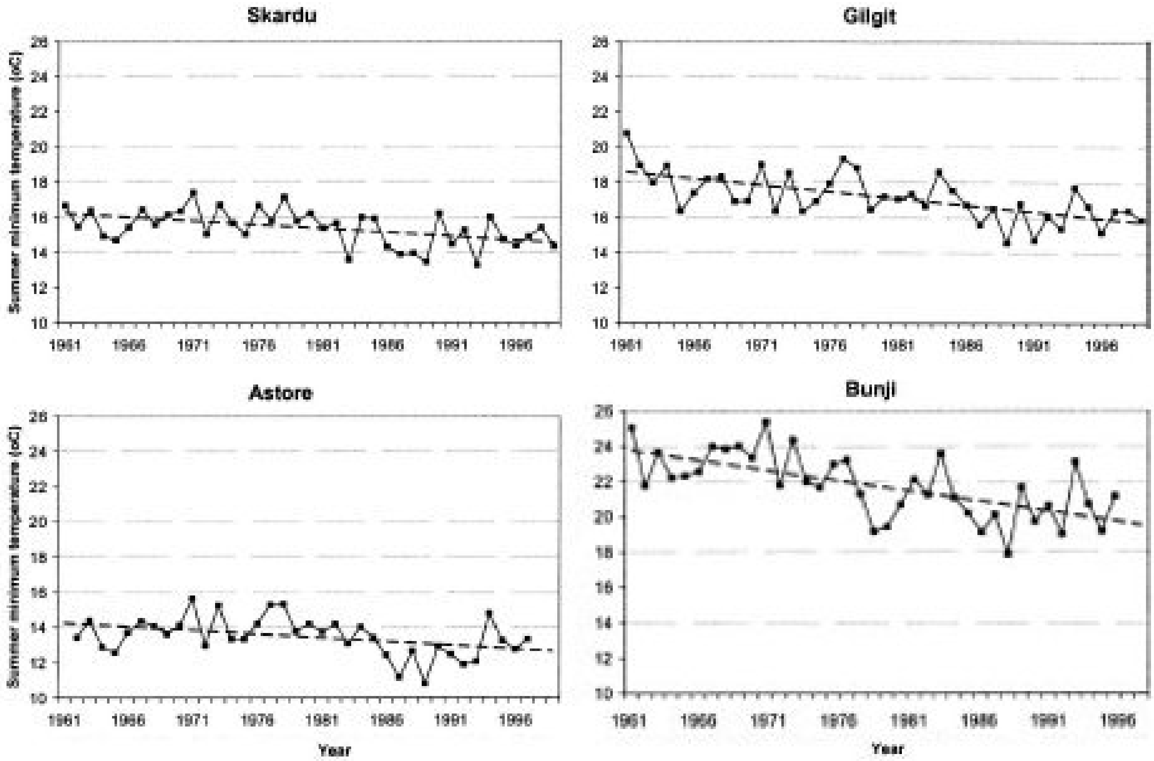

Figure 26: *Trend in summer (JJA) minimum temperature from 1961 to 1999. Panels show temperature time series with fitted linear trend line. (Fowler & Archer 2006)*

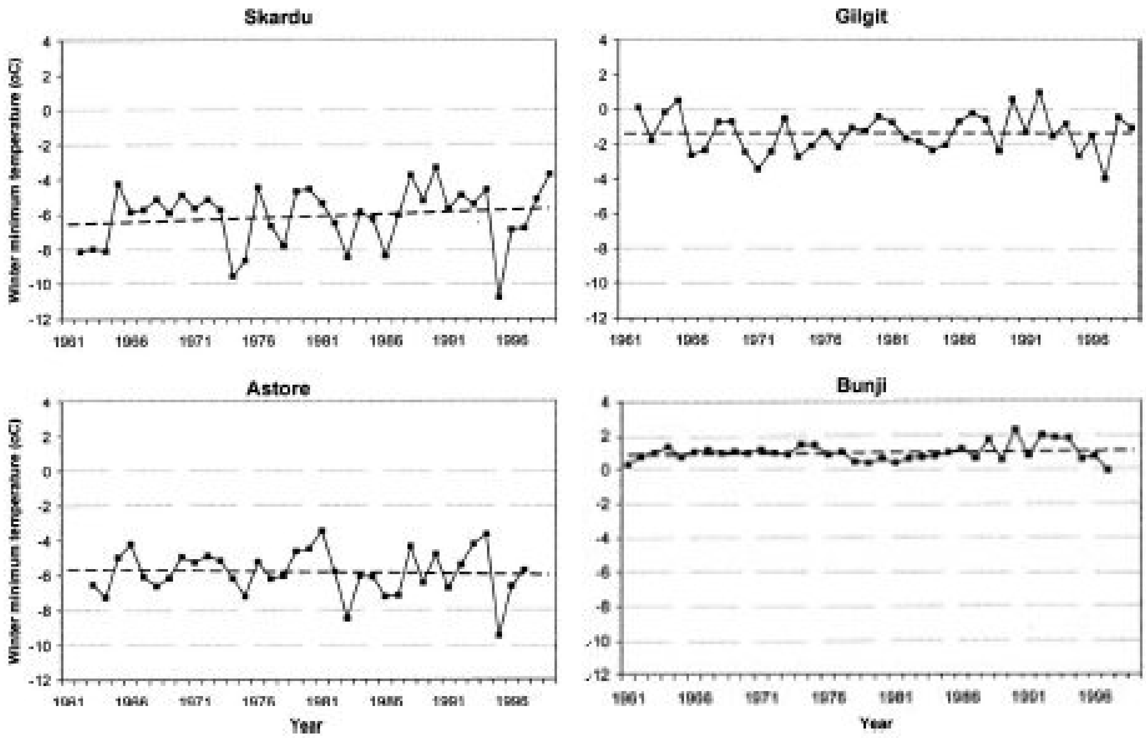

Figure 27: *Trend in winter (DJF) minimum temperature from 1961 to 1999. Panels show temperature time series with fitted linear trend line. (Fowler & Archer 2006)*

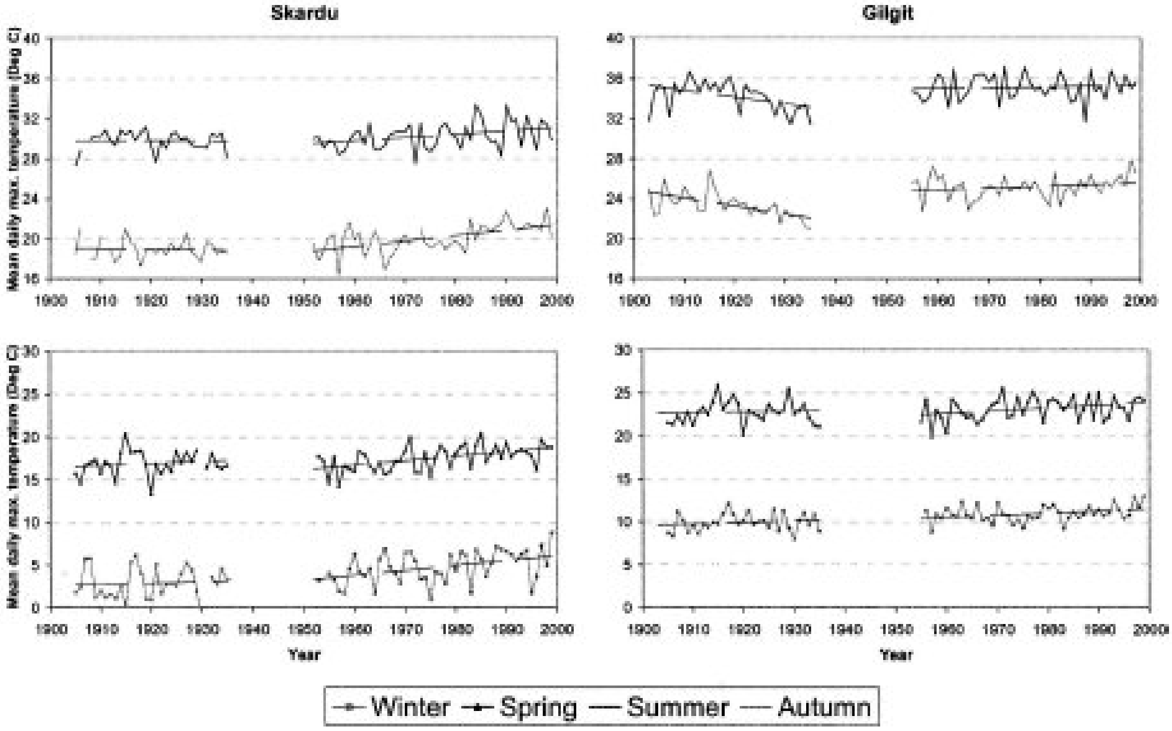

Figure 28: *Seasonal variations in maximum temperature at Skardu and Gilgit. The dashed lines represent a fitted linear trend for the periods 1905 to 1935 and 1955 to 1999: (a) summer and autumn and (b) winter and spring. Note that different scales are used for the y-axis to highlight the differences between maximum temperatures in different seasons. (Fowler & Archer 2006)*

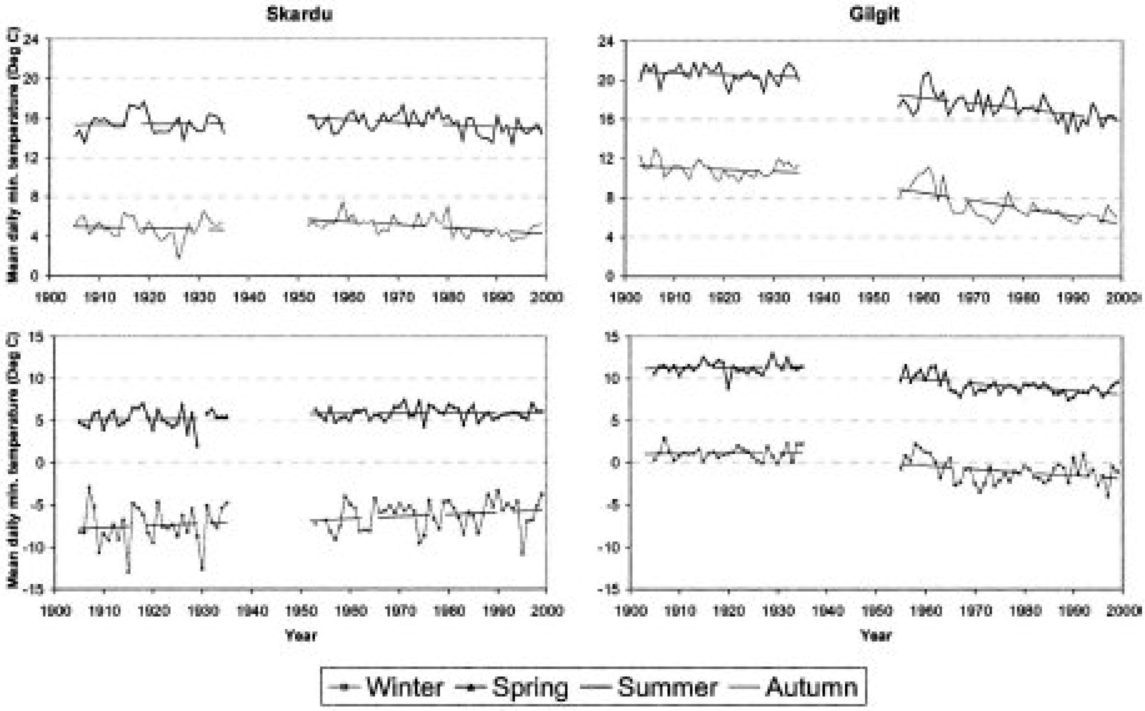

Figure 29: *Seasonal variations in minimum temperature at Skardu and Gilgit. The dashed lines represent a fitted linear trend for the periods 1905 to 1935 and 1955 to 1999: (a) summer and autumn and (b) winter and spring. Note that different scales are used for the y-axis to highlight the differences between minimum temperatures in different seasons. (Fowler & Archer 2006)*

No.	Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Chitral		**.74**	***.49***	***.57***	**.66**	***.39***	***.60***		***.54***	***.53***	.38	***.56***	***.50***	***.52***	.26	***.49***	.21
2	Drosh	**.85**		.21	.24	***.47***	.12	**.58**	.05	**.74**	***.50***	**.57**	**.69**	**.64**	**.69**	**.75**	**.74**	**.61**
3	Gilgit	***.51***	***.33***		**.69**	**.68**	**.46**	**.38**	-.14	***.35***	***.42***	**.59**	***.48***	***.49***	***.52***	***.43***	***.58***	.28
4	Bunji	.22	.15	**.69**		**.62**	**.59**	***.36***		***.38***	***.38***	***.53***	.31	***.35***	***.37***	.32	***.49***	.19
5	Astore	***.51***	***.44***	**.67**	**.70**		**.57**	**.78**	-.13	**.58**	.48	**.67**	**.74**	**.67**	**.64**	***.63***	**.66**	**.56**
6	Skardu	.35	.25	**.56**	**.59**	**.77**		**.68**	.26	.25	***.39***	.27	***.38***	***.41***	.25	.23	.35	.28
7	Srinagar	-.12	-.10	.10	.29	.13	.27		***.31***	**.84**	**.57**	**.71**	**.89**	**.76**	**.69**	***.63***	**.79**	**.67**
8	Leh		.17	-.14		**.60**	.05	***.30***										
9	Dir	.35	***.41***	.31	.32	.24	-.06	.30			***.49***	**.57**	**.79**	**.78**	**.67**	***.53***	**.75**	**.77**
10	Shahpur	.09	.16	.07	.22	.09	.05	.12		.15		**.58**	***.46***	***.44***	***.39***	***.55***	**.73**	.32
11	Puran	.20	.25	-.10	-.01	-.04	.05	.12		.33	**.60**		**.69**	**.62**	**.62**	***.61***	**.76**	.49
12	Besham	***.43***	***.54***	.10	.07	.24	.14	.22		.38	.08	.29		**.90**	**.91**	**.71**	**.90**	**.79**
13	Oghi	.00	.00	***-.45***	***-.44***	***-.40***	-.25	.13		.16	***.36***	***.43***	.28		**.73**	***.57***	**.83**	**.81**
14	Shinkiari	-.25	-.13	-.19	-.11	-.11	-.07	.05		-.09	.22	.25	.22	***.37***		**.81**	**.93**	**.67**
15	Balakot	-.16	-.14	-.05	-.32	-.41	-.29	-.07		-.02	.45	.37	.00	***.60***	**.70**		**.72**	***.67***
16	Muzaffarabad	-.09	-.28	-.11	-.15	-.12	-.01	.18		-.03	.11	.22	-.08	***.51***	***.42***	***.61***		**.69**
17	Tarbela	***-.58***	***-.43***	***-.41***	***-.31***	***-.44***	***-.38***	.17		-.03	-.09	-.06	-.06	.31	.31	.33	.28	

Notes:
Bold P < .001
Bold Italic P < .05
Highlighted **Negative correlation**

Figure 30: *Seasonal rainfall correlation between stations in the upper Indus basin 1961-1999. (a) (Upper triangle) October to March (b) (Lower triangle) April to September (Fowler & Archer 2004)*