Impact of Climate Change on Fresh Water Resources of Pakistan

Ghazanfar Ali
Global Change Impact Studies Center, Islamabad

IUCN Climate Change Seminar, Muzaffarabad, Azad Jammu & Kashmir
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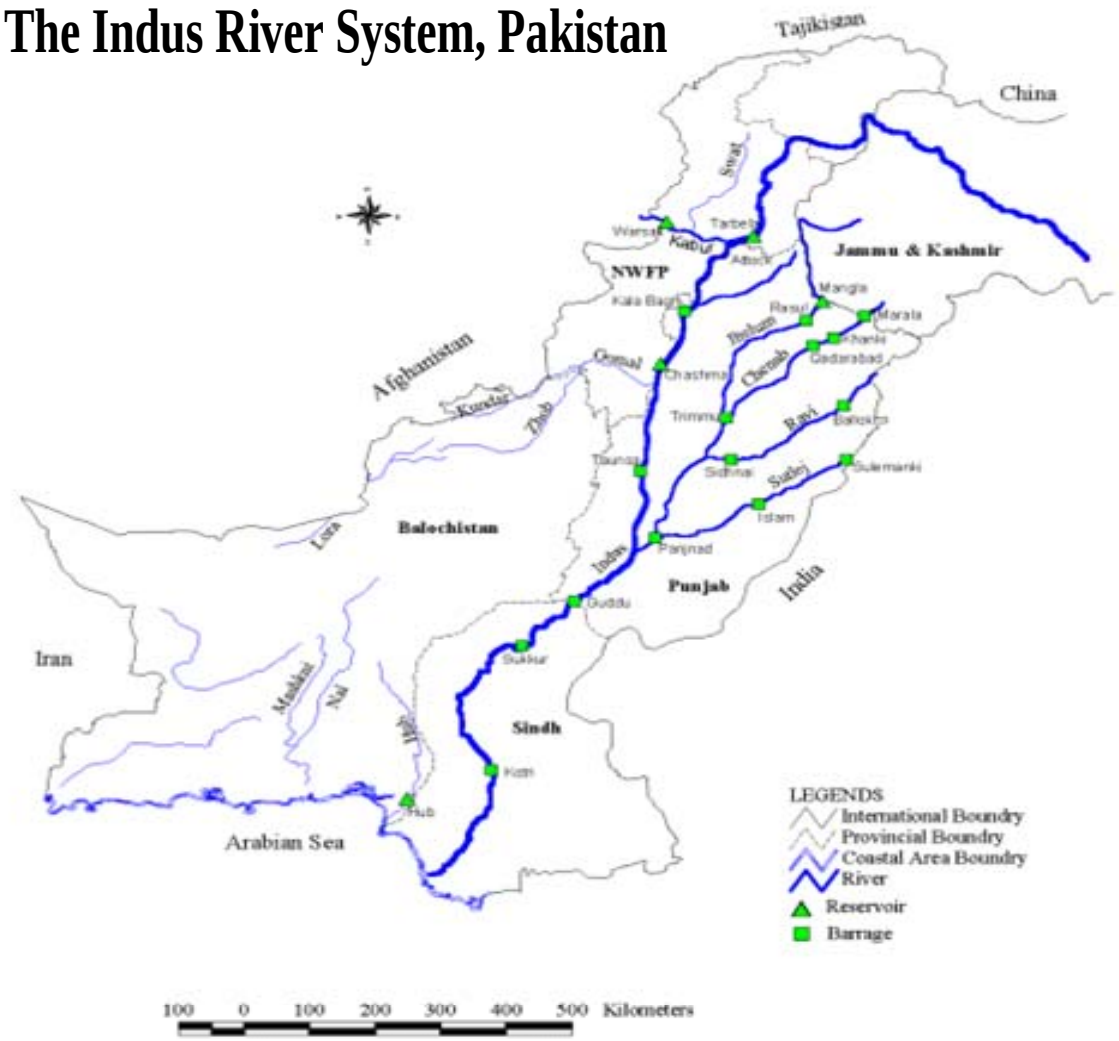
Water Resources of Pakistan

- Some Characteristics of Pakistan‘s Water Resources
- Climate Change Concerns
- Implications and Adaptation

The Indus River System, Pakistan



Distribution of Water in Main Rivers of Pakistan

	% of IRS Inflows	% Seasonal Distribution		Dominant Source in Summer	Dominant Source in Winter
		Summer (Apr-Sep)	Winter (Oct-Mar)		
Indus	44	86	14	Snow/Glacial melt	Winter Rainfall + Baseflow
Chenab	19	83	17	Snow/Glacial melt + Monsoon	Winter Rainfall + Baseflow
Jhelum	16	78	22	Mainly Snow melt + Monsoon	Winter Rainfall + Baseflow
Kabul	16	82	18	Snow/Glacial melt	Winter Rainfall + Baseflow
Others	5				

Some Concerns of Pakistan‘s Water Resources

- Decreasing Per Capita Water Availability
- Large Intra-annual Variability in Annual River Flows
- Inadequate Storage Capacity and Capacity Loss with Time
- Inadequate Discharge to Sea for Preventing Sea Water Intrusion and Other Related Issues

Some Characteristic of Pakistan's Water Resources

- **Water Availability Per Capita (m^3)**

Year	1951	2003	2007	2020 (projected)
Availability	5650	1200	1100	855

- **IRS Inflows (1976-77 to 2002-03)**

	Annual	In Kharif (Apr-Sep)	In Rabi (Oct-Mar)
Average (76-77 to 2002-03)	141 MAF	82%	18%
Maximum (in 1991-92)	172 MAF		
Minimum (in 2001-02)	97 MAF		

- **Reservoir Capacity (Mangla + Chashma + Tarbela)**
  - Original : 18.4 MAF (≈ 13 % of Average Annual Flows)
  - Year 2001 : 14.1 MAF (≈ 10 % of Average Annual Flows)
  - Projected 2010 : 12.4 MAF (≈ 9 % of Average Annual Flows)
- **Downstream Kotri Annual Discharges (1976-77 to 2002-03)**
  - Average : 35 MAF
  - Maximum (in 1994): 92 MAF (IRS Inflows in 1994: 166 MAF)
  - Minimum (in 2000): 0.7 MAF (IRS Inflows in 2000: 103 MAF)

Source of data: WAPDA

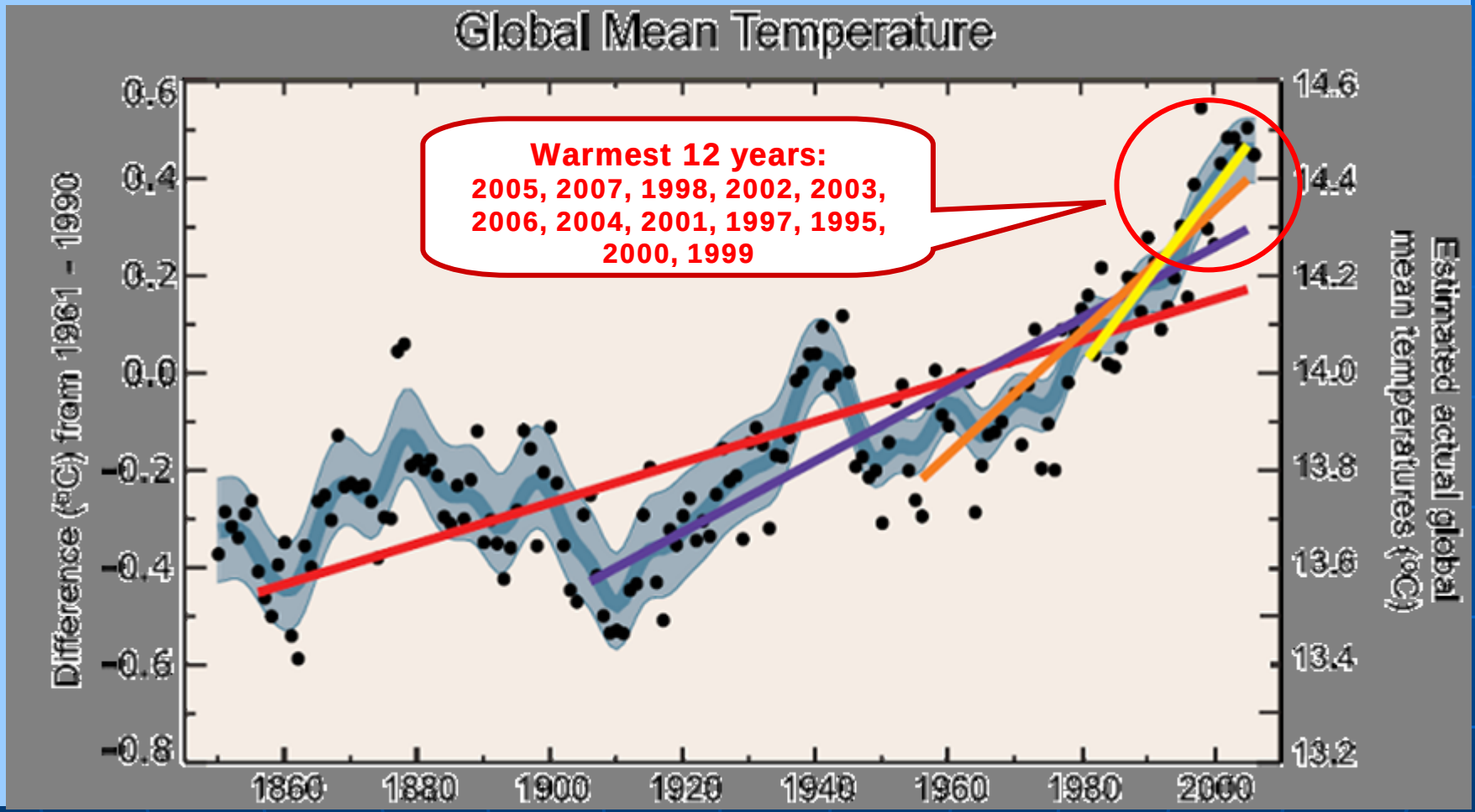
Climate Change

"the greatest challenge facing the world at the beginning of the century"

World Economic Forum
Davos, Switzerland 2000

Major Climate Change related Concerns for Water Resources of Pakistan

- Melting of HKH glaciers and its Implications for:
  - Average Annual River Flows
  - Pattern of Seasonal Flows
  - Inter Annual Variability of Flows
- Increase in Frequency and Intensity of Extreme Precipitation Events and its Implication for Floods and Droughts
- Sea-level Rise and its Implications



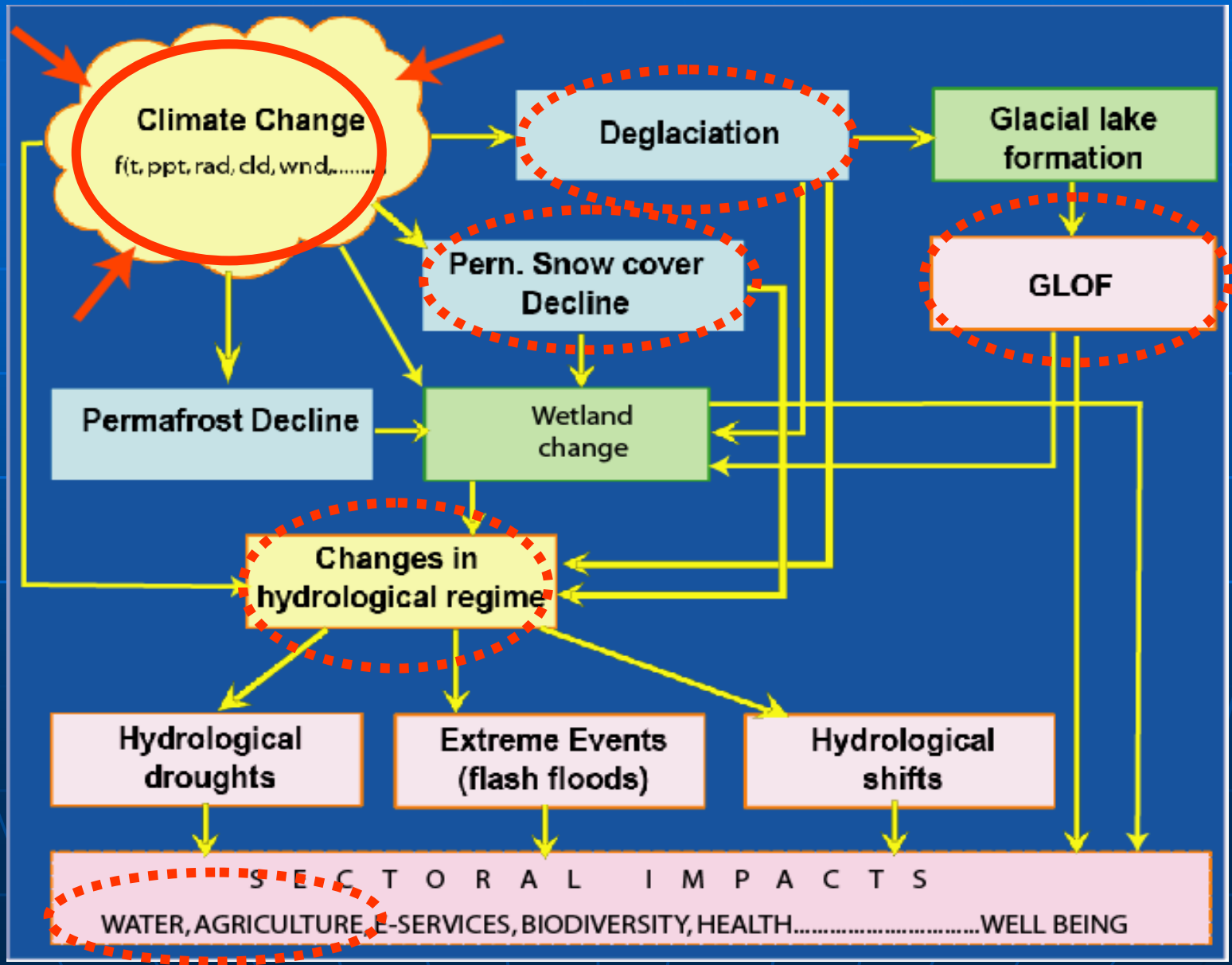
Rate of Change (°C per decade)

1850 – 2005	0.045
1905 – 2005	0.074
1955 – 2005	0.128
1980 – 2005	0.177

Average Global Temperature °C

1999	14.38
2000	14.40
1995	14.48
⋮	
1998	14.57
2007	14.60
2005	14.63

Climate Change and Water



Upper Indus Basin (UIB), Northern Pakistan

De-glaciations World Wide

- According to Haeberli and Hoelzle (2001) of the World Glacier Monitoring Service (WGMS), the measurements taken over the last century "clearly reveal a general shrinkage of mountain glaciers on a global scale"

- It was forecast by IPCC in its Second Assessment Report (1996) that up to a quarter of global mountain glacier mass could disappear by 2050 and up to half could be lost by 2100.

Snow & Glacier Melt Contribution

- **Glaciers in Pakistan cover 13,680 sq. km area which is 13% of mountain regions of the Upper Indus Basin (UIB)**

- **Glacial and snow melt water makes more than 80% contribution to the flows of UIB rivers**

- **"Glaciers in Himalayas are receding faster than in any other part of the world and, if the present rate continues, the likelihood of their disappearing by the year 2035 is very high".**

A conclusion reached by the 1999 report of the Working Group of Himalayan Glaciology (WGHG) of the International Commission for Snow and Ice (ICSI).

Projected Changes in Indus River Flows due to Melting of HKH Glaciers

(Reported by Some Recent Studies)

- **Glacier melt in the Himalayas is projected to increase flooding within next two to three decades. This will be followed by decreased river flows as the glaciers recede.**

  (IPCC Fourth Assessment Report, Summary for Policy Makers of WG-II released on April 6th, 2007)

- **Western Himalayan glacier will retreat for the next 50 years causing increase of Indus River flows. Then the glacier reservoirs will be empty, resulting in decrease of flows by up to 30% to 40% over the subsequent fifty years.**

  ("Pakistan's Water Economy: Running Dry", a World Bank Report, 2006)

- **As a result of glacier melting, Upper Indus will show initial increase between +14% and +90% in mean flows over the first few decades of the next 100 years, to be followed by flows decreasing between -30% and -90% of the baseline by the end of this century.**

  (Technical Report: Snow and Glaciers Aspects of Water Resources Management in the Himalayas, Centre of Ecology and Hydrology, Wallingford, UK, April 2004).

Recent Conflicting Reports about Recession of Himalayan Glaciers

- In 2005, Hewitt reported widespread evidence of glacier expansion in the late 1990s in the Central Karakoram, in contrast to a worldwide decline of mountain glaciers.

  (K.Hewitt in Mountain Research and Development Vol. 25, No.4, Nov 2005)

- Based on surveys between 1997 and 2002, he reported that some of the large Karakoram glaciers - 40 to 70 km in length - exhibited 5 to 15 m of thickening over substantial ablation zone areas, locally more than 20 m.

- These conflicting findings make the impact of climate change on Karakoram glaciers and Indus River flows very uncertain.

Climate Change Science Studies in Pakistan

- Climate Change research remained essentially neglected in Pakistan until recently;
- **2001:** Establishment of a multi-disciplinary effort in this direction proposed by Dr. Ishfaq Ahmad, Special Advisor to the Prime Minister;
- **May 2002:** Global Change Impact Studies Centre (GCISC) established with seed money provided by Ministry of Sc & Tech; GCISC now being supported by Planning Commission.
- **January 2005:** Prime Minister's Committee on Climate Change established, with GCISC as its Secretariat.
- **Dec., 2006:** GCISC attached to National Centre for Physics as an autonomous organization.

GCISC Objectives

The main objectives of the Centre are:

- to keep a track of the current and likely future trends of Climate Change;
- to develop a national capacity for Climate Change research;
- to analyse and evaluate the impacts of Climate Change on key sectors e.g. Food and Water security;
- to raise public awareness of Climate Change related issues.

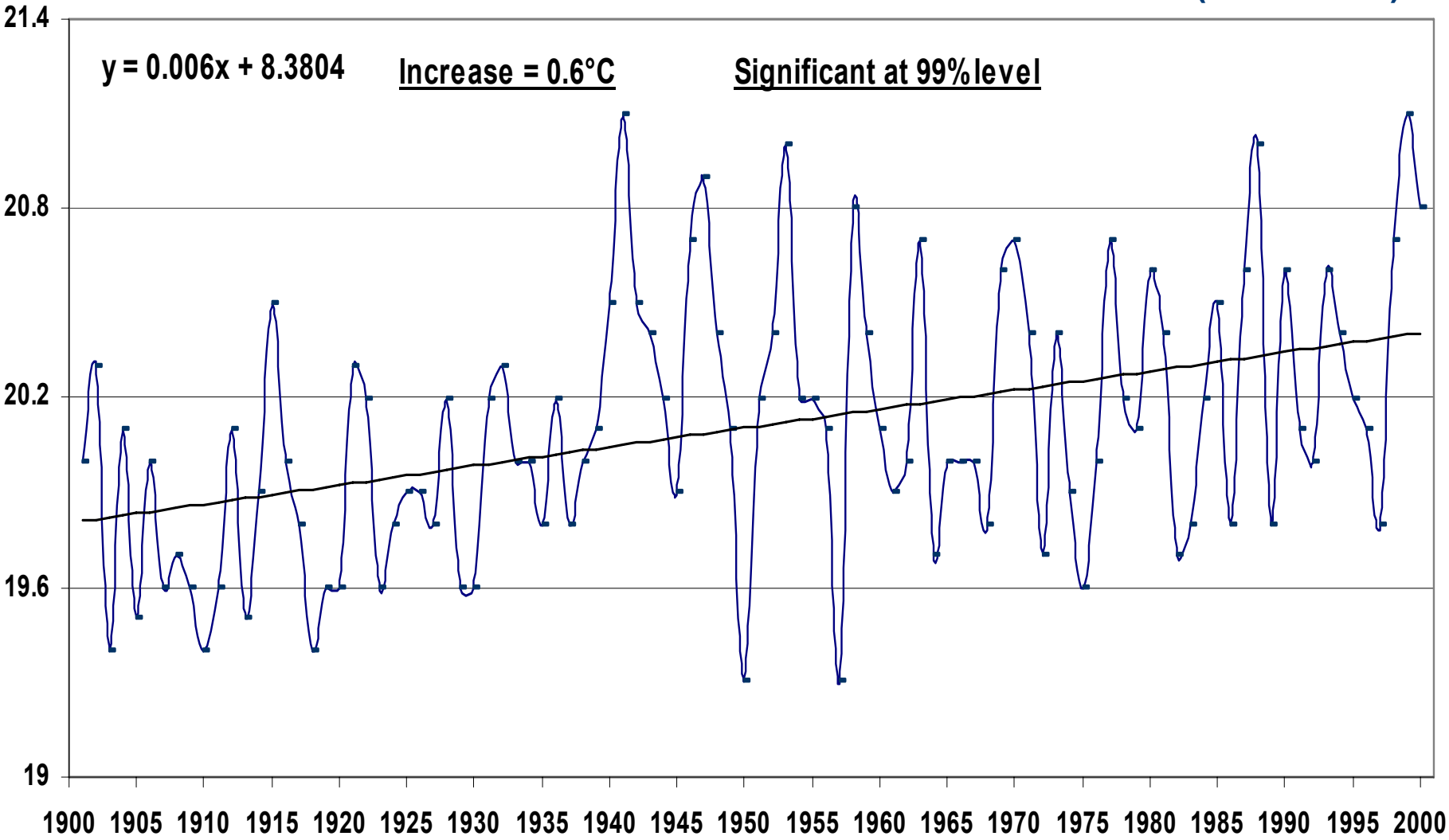
Exploring the CC Impacts

- Trends of Temperature and Precipitation
- Monitoring of glaciers in the Hindu Kush – Karakoram – Himalaya (HKH) region
- Trends of flow in the rivers of the Indus Basin
- Projection of flows in the river of the Indus Basin in the light of CC scenarios
- Impact of temperature increase and glacier retreat on Indus River flows

Temperature and Precipitation Trends

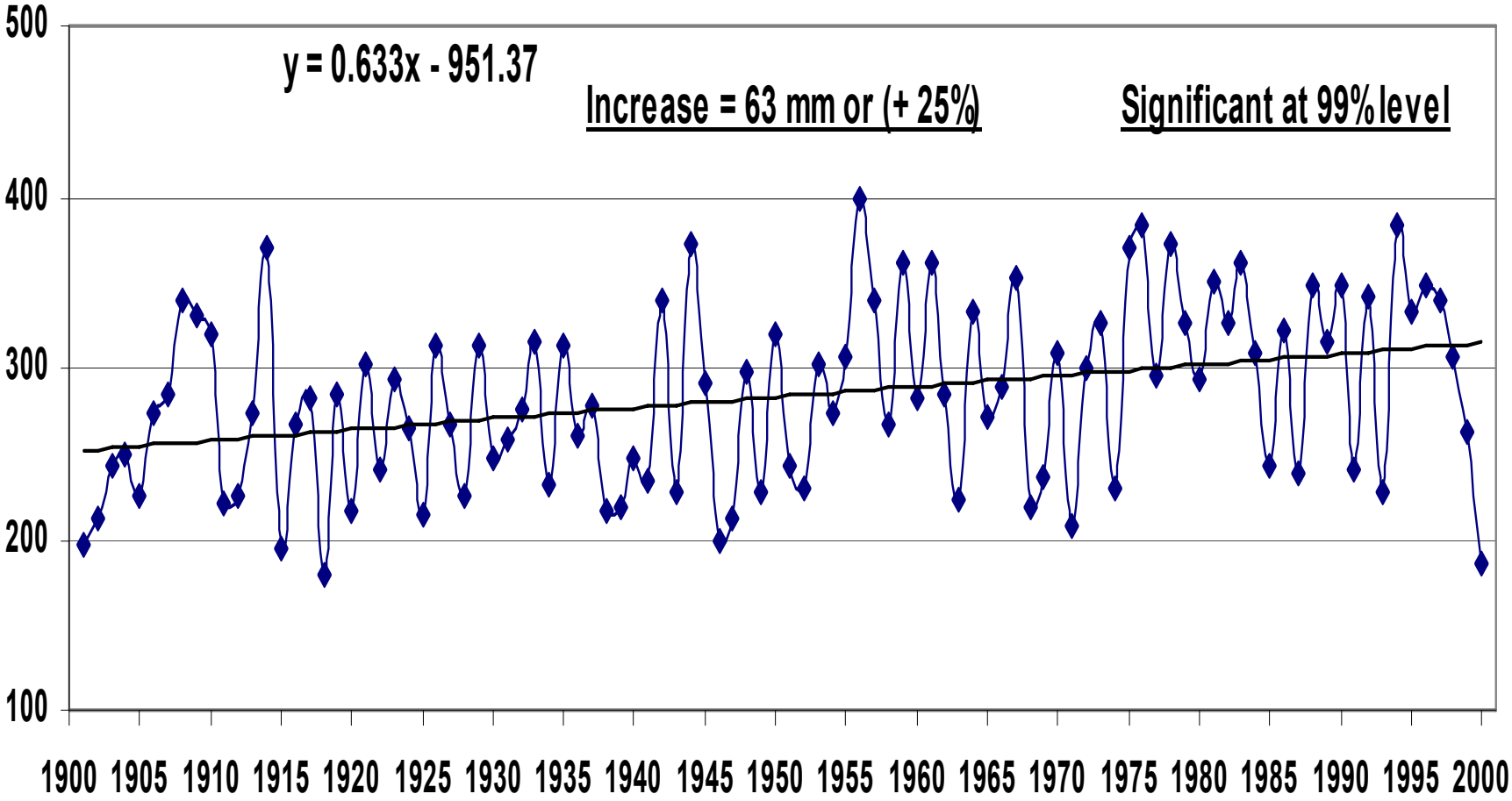
Mean Temperature (°C) Trend 1901-2000 for Pakistan

(CRU data)

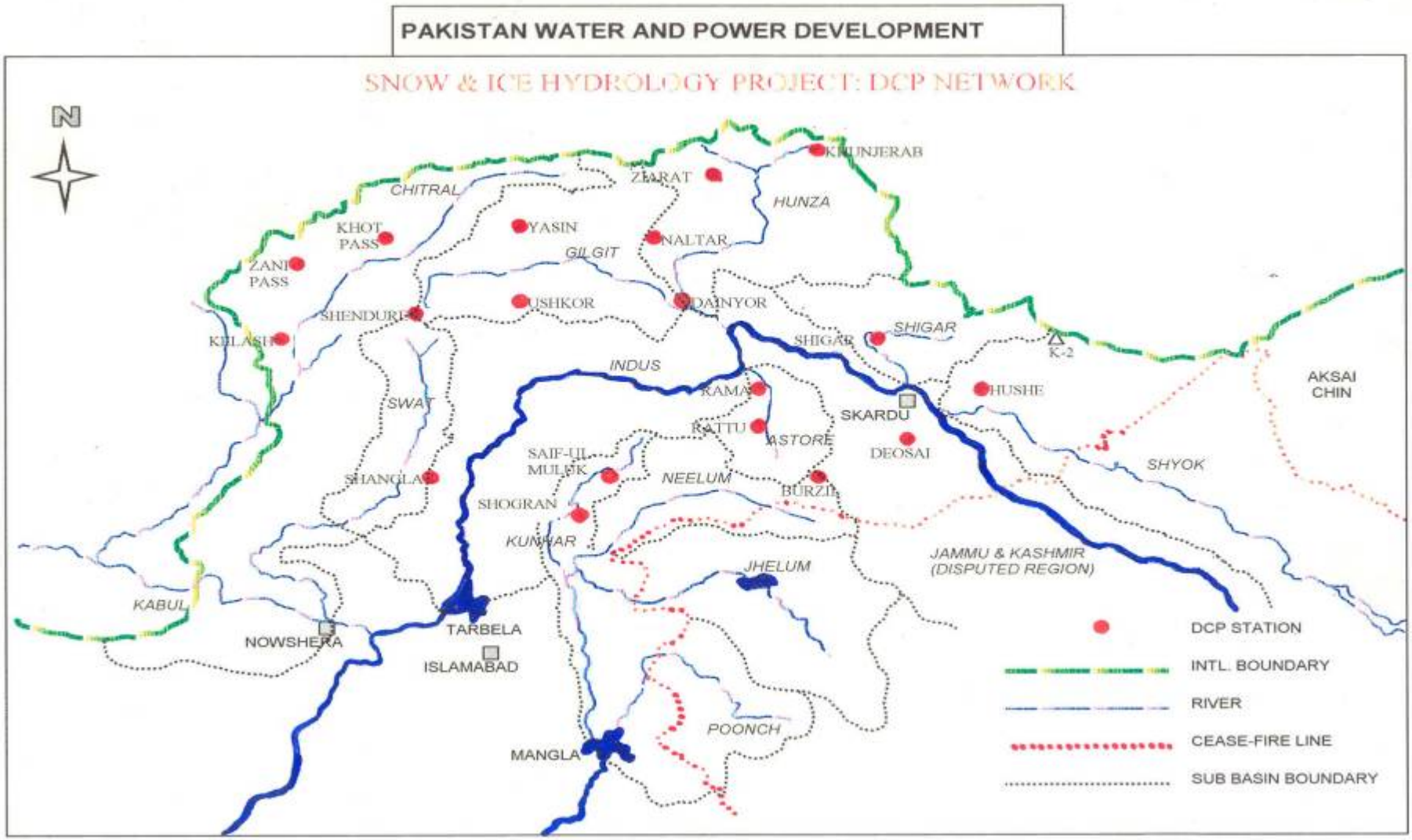


Annual Precipitation (mm) Trend 1901-2000 for Pakistan

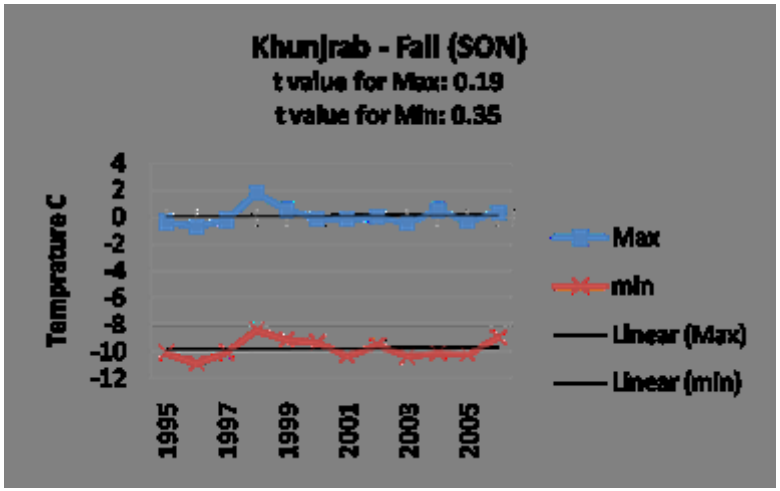
(CRU data)

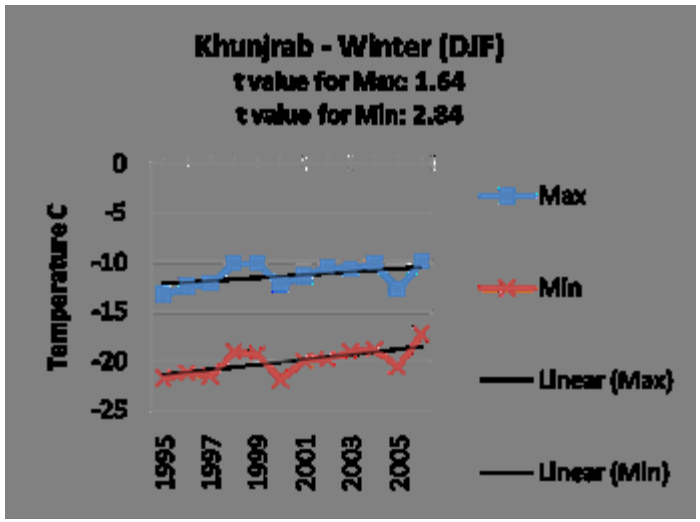


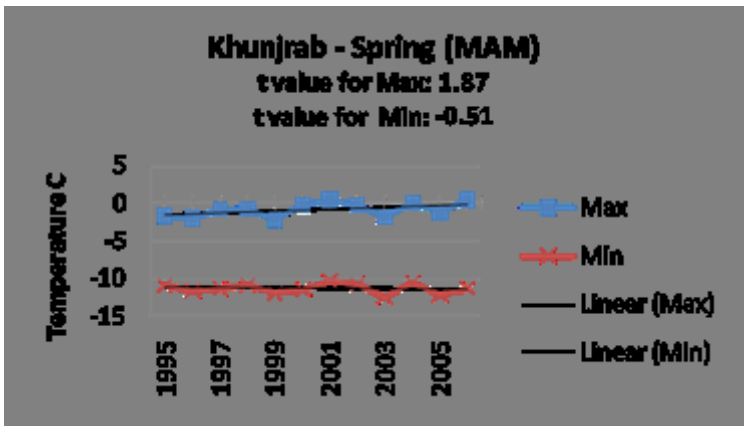
UIB Map showing High Elevation Met Stations

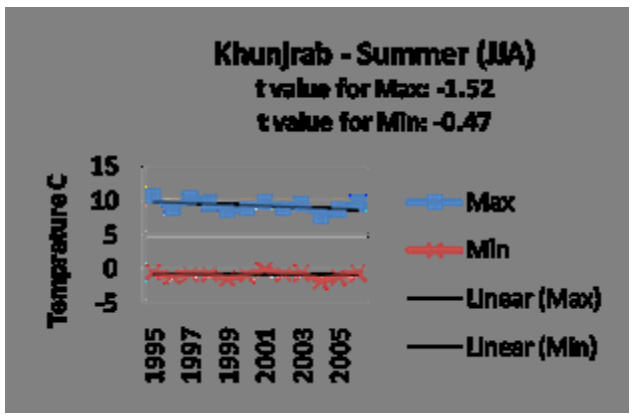


Khunjerab DCP Station (Elevation 4730 m.a.s.l)

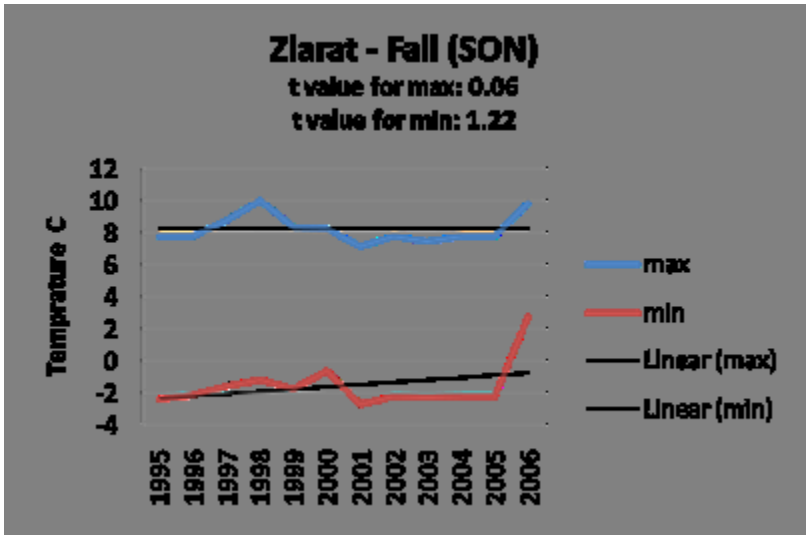


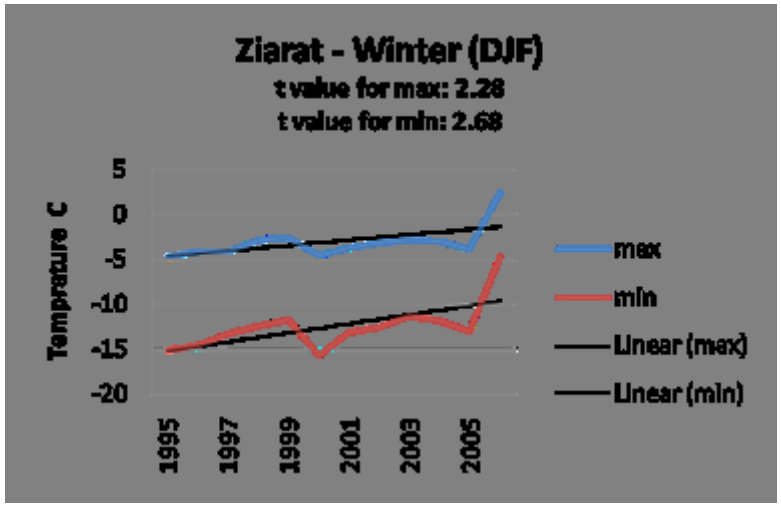


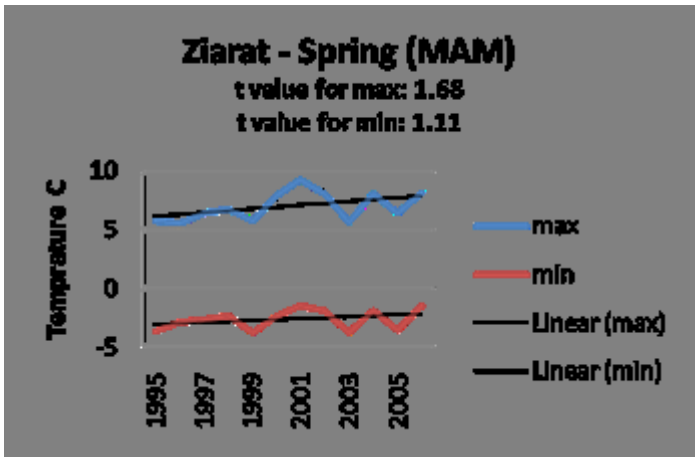


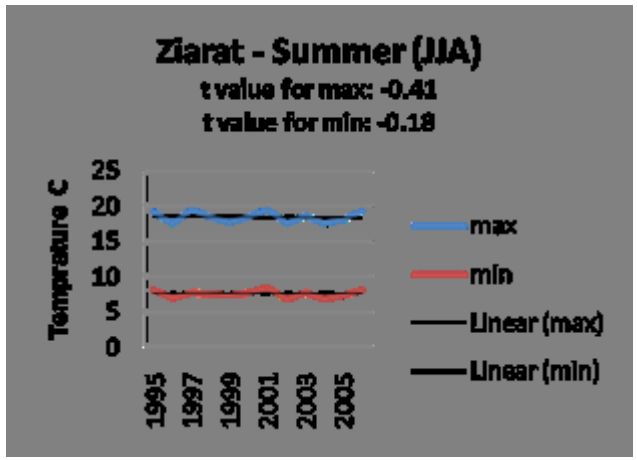


Ziarat DCP Station (Elevation 3669 m.a.s.l)

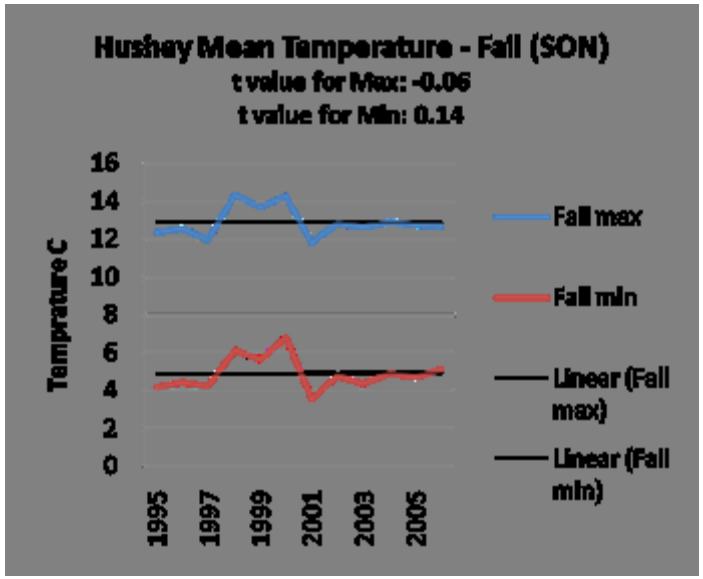


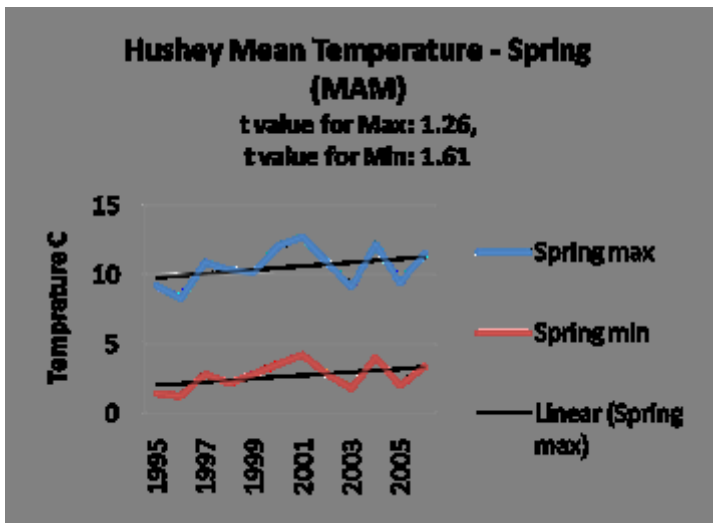


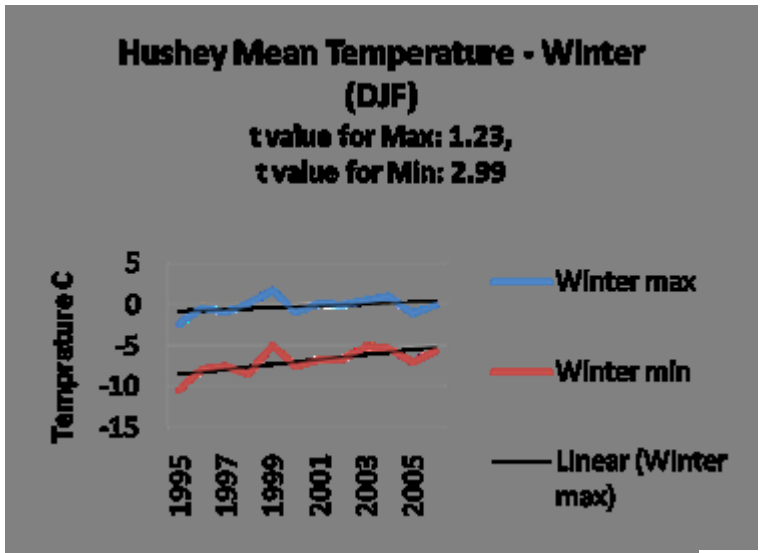


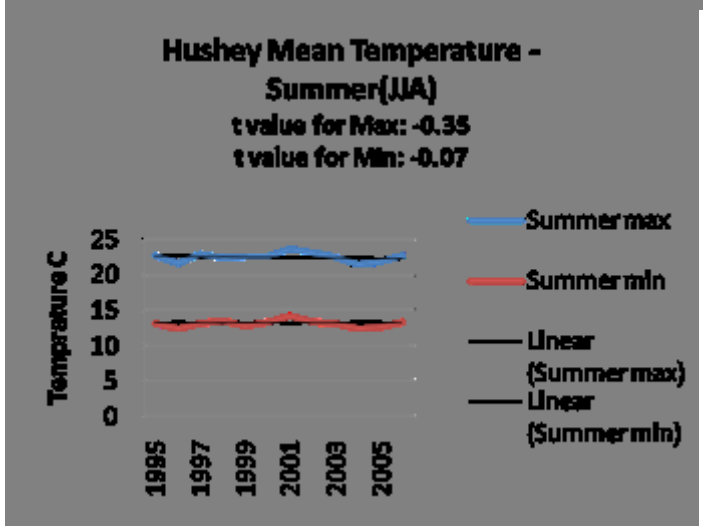


Hushey DCP Station (Elevation 2995 m.a.s.l)

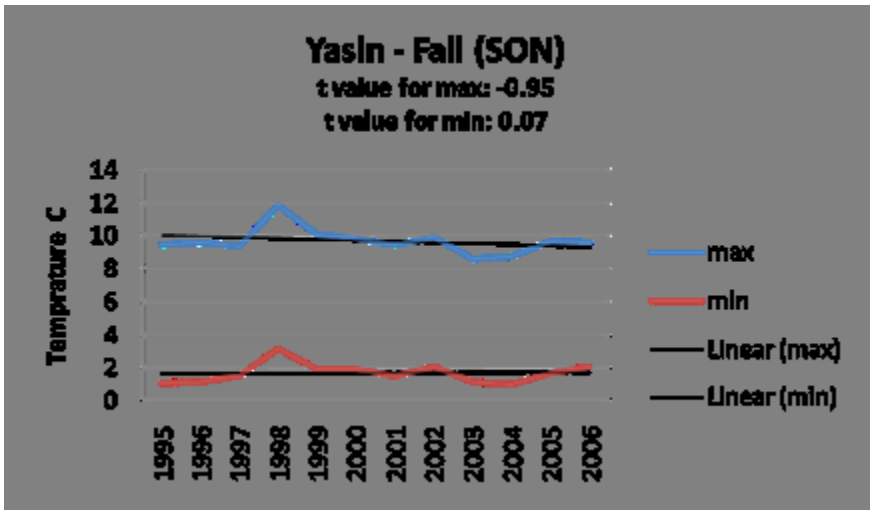


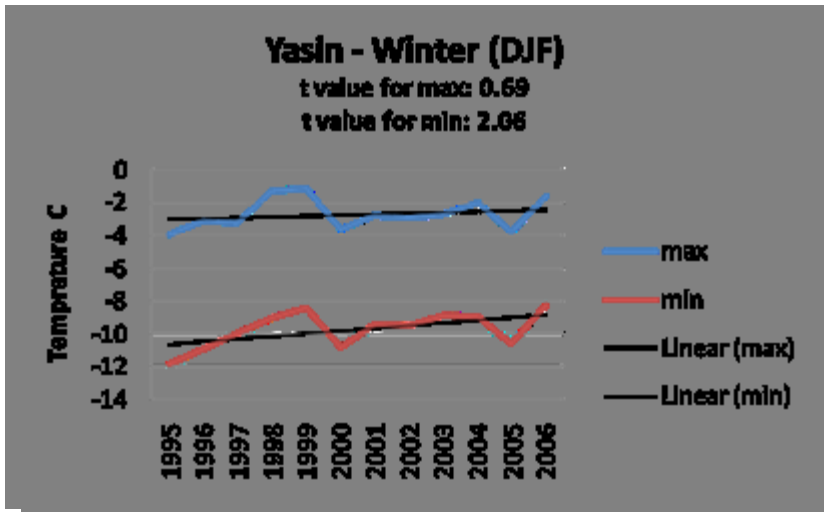


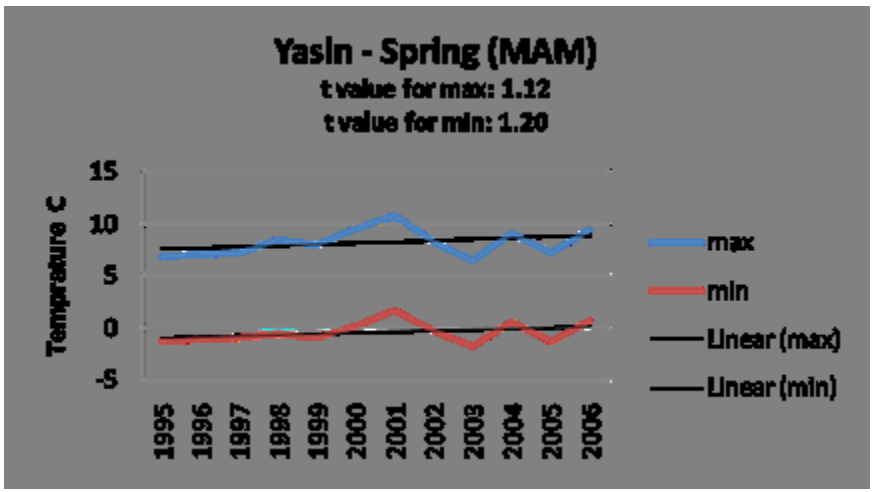


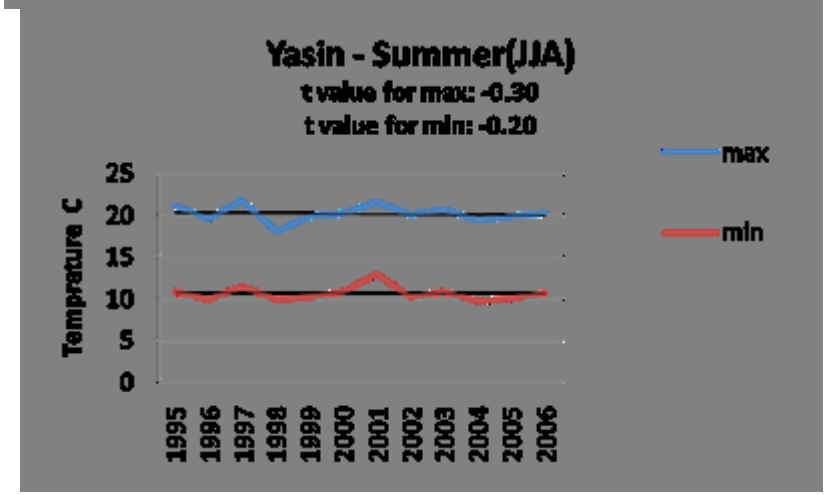


Yasin DCP Station (Elevation 3150 m.a.s.l)

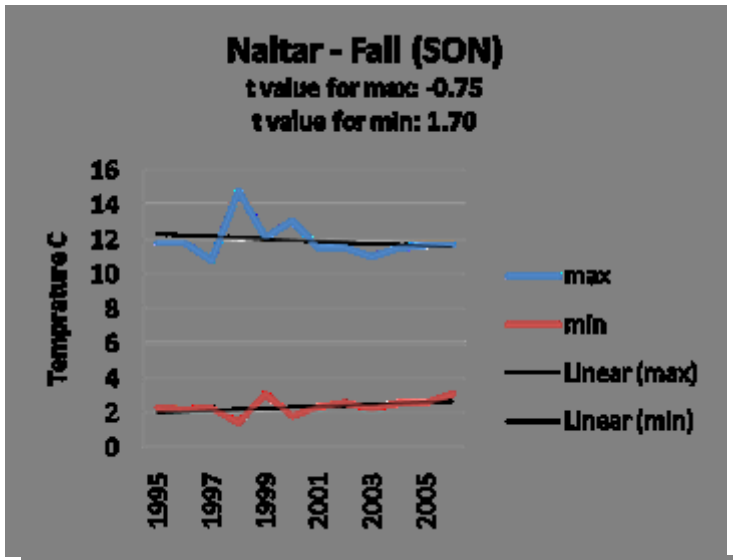


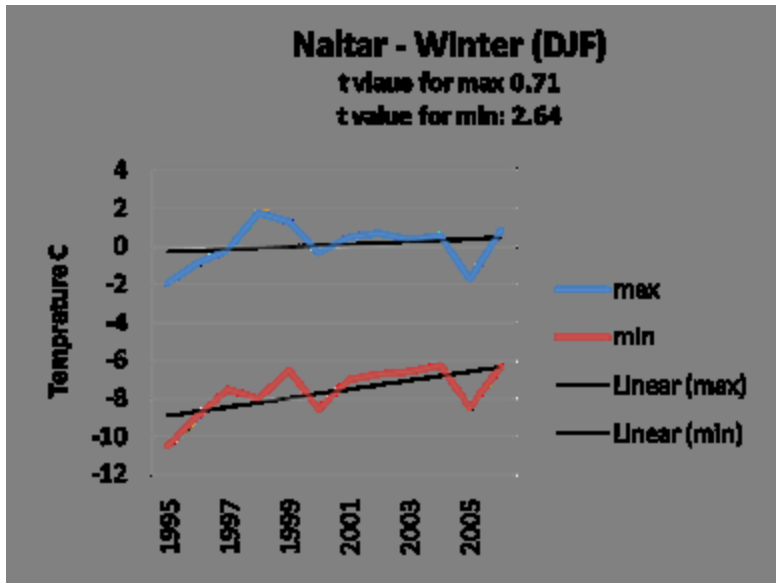


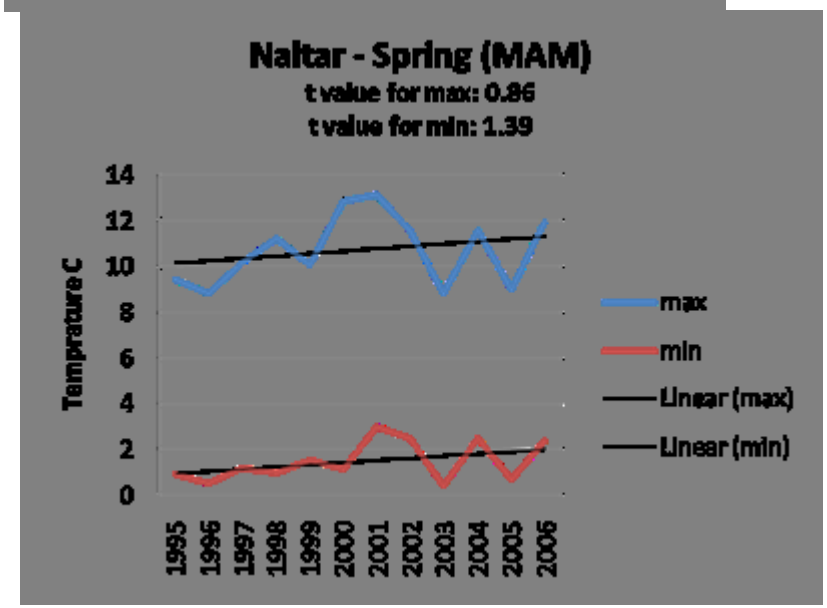


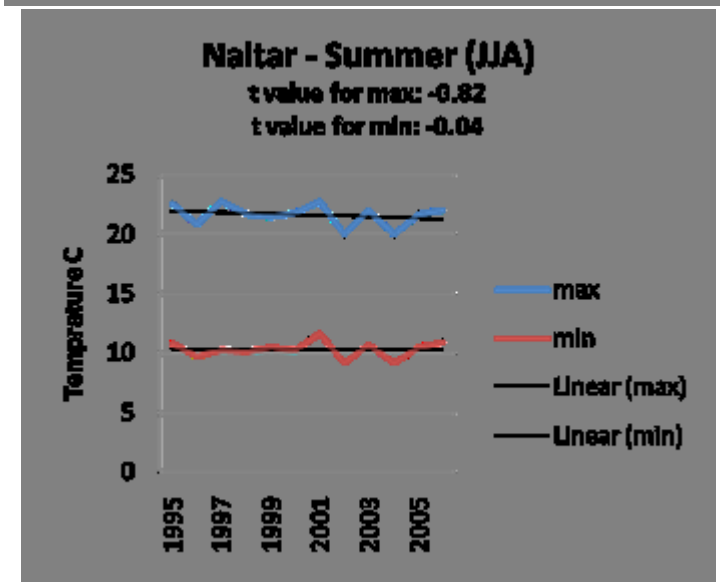


Naltar DCP Station (Elevation 2810 m.a.s.l)

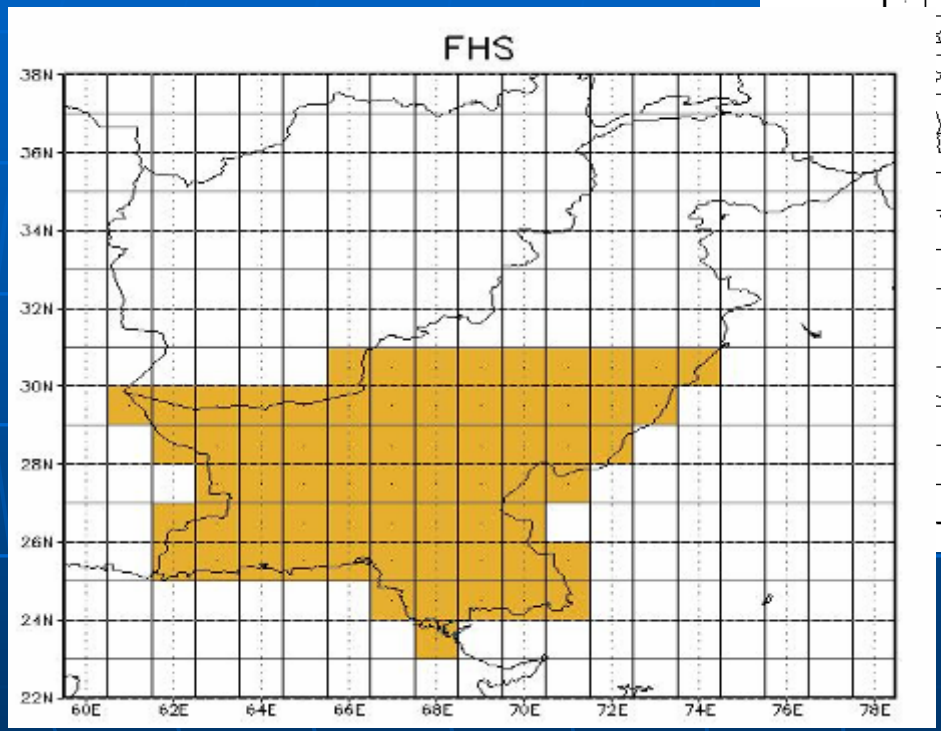


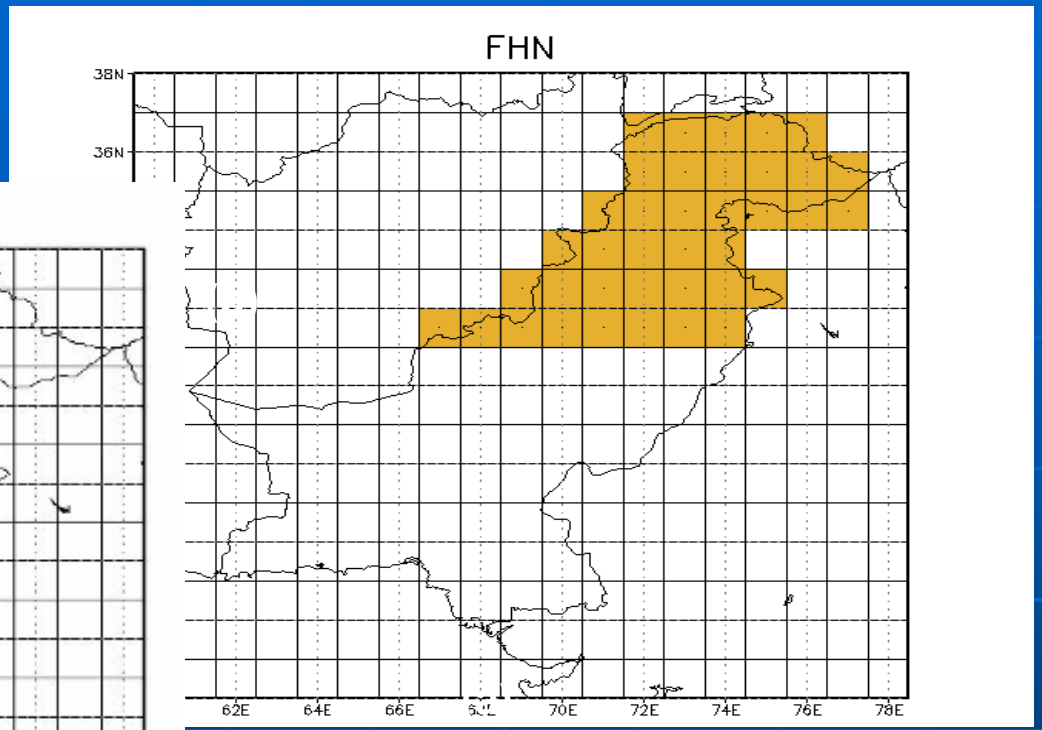






Northern and Southern Parts of Pakistan





(b)

Grids covering geographical areas of:

a) Northern (FHN) and
b) Southern (FHS) parts of Pakistan

Projected Temperature Changes, ΔT (° C) by Various GCMs

Northern Pakistan

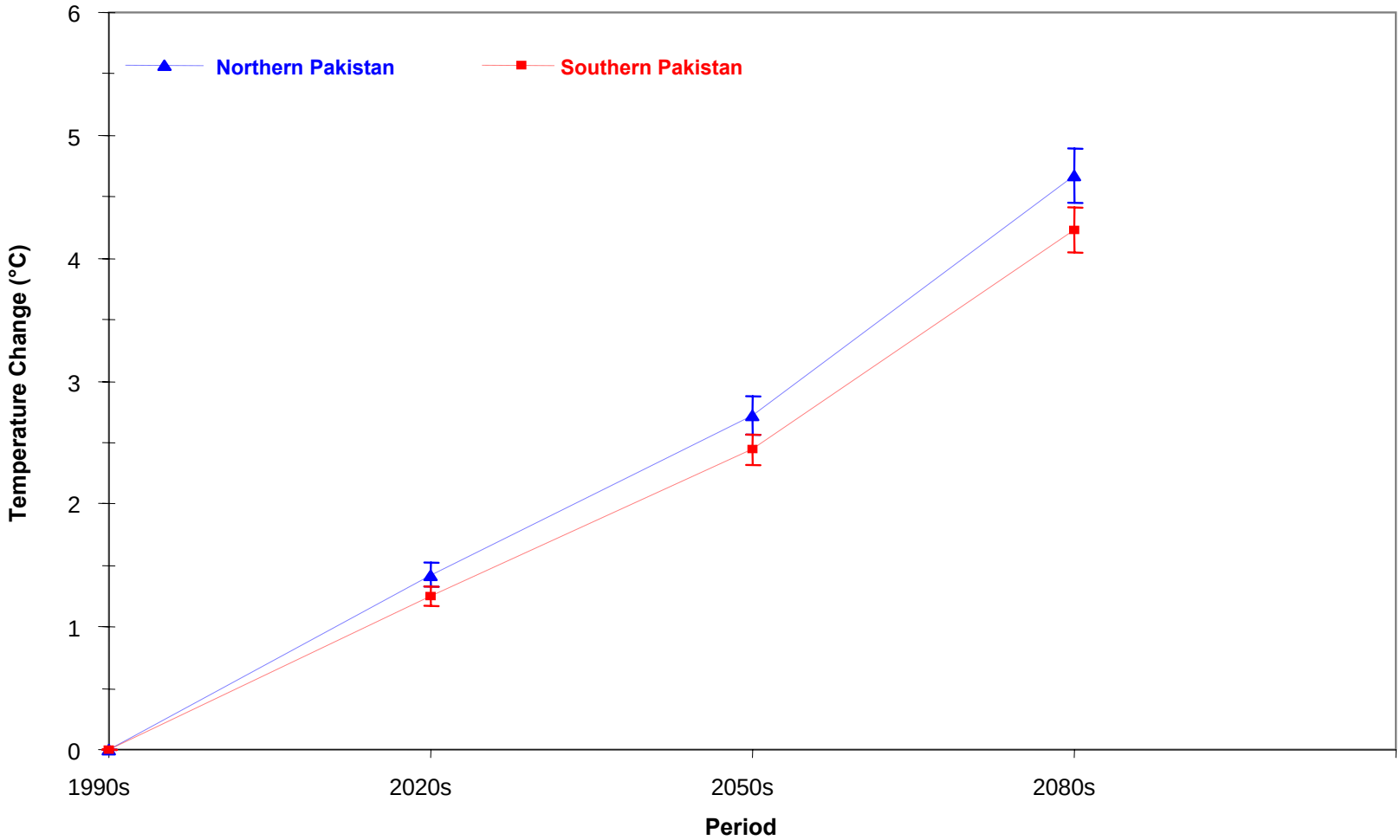
Region:FHN	A2			A1B		
	2020s	2050s	2080s	2020s	2050s	2080s
Annual	1.42 ± 0.10	2.72 ± 0.16	4.67 ± 0.23	1.55 ± 0.10	2.95 ± 0.15	4.12 ± 0.23
Summer	1.31 ± 0.12	2.62 ± 0.20	4.56 ± 0.28	1.45 ± 0.12	2.91 ± 0.18	4.07 ± 0.26
Winter	1.52 ± 0.11	2.82 ± 0.19	4.72 ± 0.24	1.67 ± 0.12	3.02 ± 0.17	4.11 ± 0.24

Southern Pakistan

Region: FHS	A2			A1B		
	2020s	2050s	2080s	2020s	2050s	2080s
Annual	1.25 ± 0.08	2.44 ± 0.13	4.22 ± 0.18	1.40 ± 0.09	2.64 ± 0.13	3.73 ± 0.18
Summer	1.10 ± 0.13	2.24 ± 0.20	3.90 ± 0.26	1.23 ± 0.12	2.43 ± 0.17	3.50 ± 0.22
Winter	1.38 ± 0.09	2.57 ± 0.13	4.33 ± 0.18	1.57 ± 0.10	2.81 ± 0.14	3.81 ± 0.19

Projected Changes in Average Temperature of Northern and Southern Pakistan

(Corresponding to IPCC A2 Scenario)



Projected Precipitation Changes, ΔP (%) by Various GCMs

Northern Pakistan

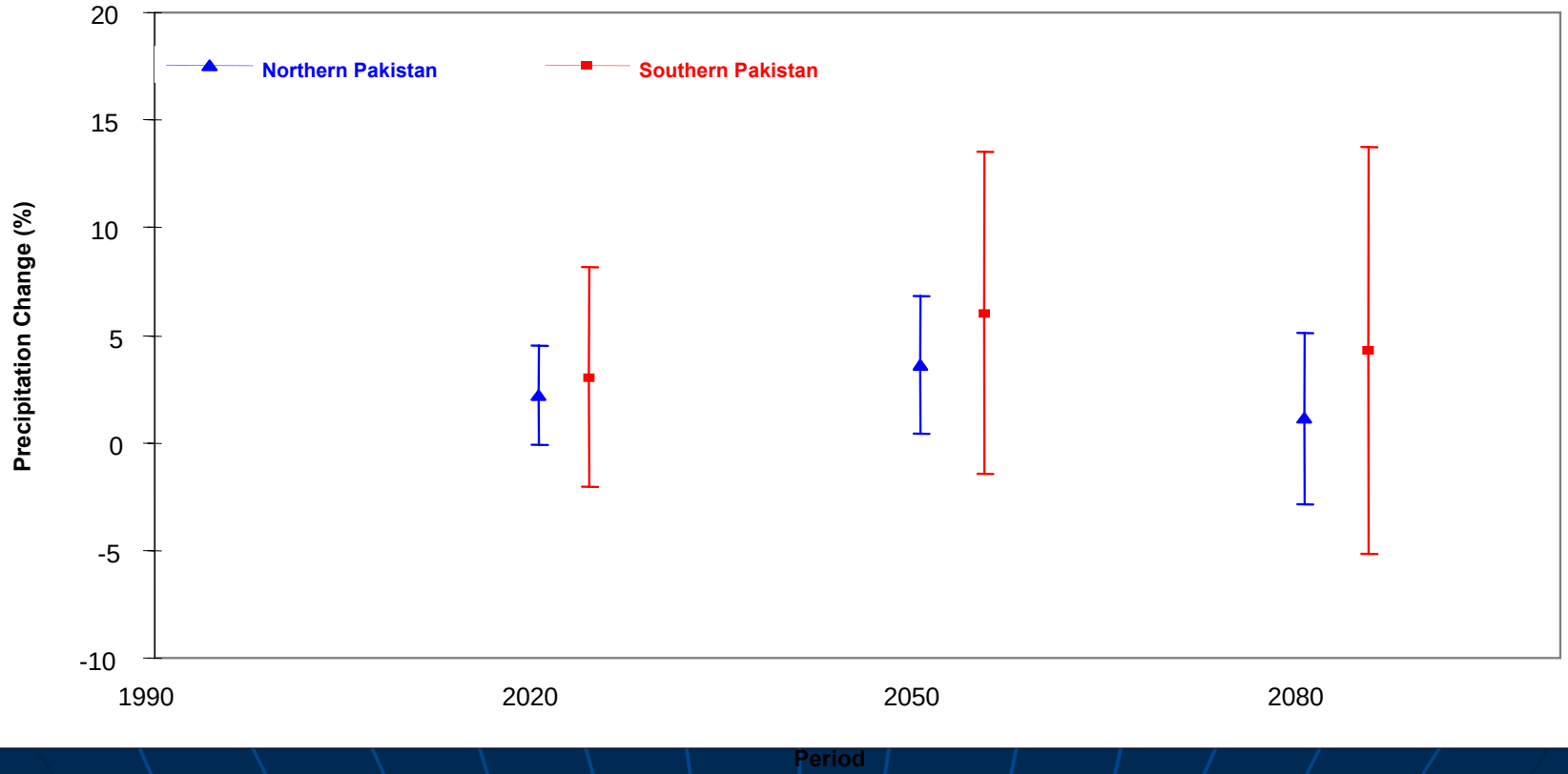
Region: FHN	A2			A1B		
	2020s	2050s	2080s	2020s	2050s	2080s
Annual	2.22 ± 2.29	3.61 ± 3.21	1.13 ± 3.95	- 0.74±1.48	- 1.78±2.18	- 0.73±3.08
Summer	5.52 ± 3.69	7.63 ± 6.52	1.08 ± 8.35	1.33 ± 3.03	1.81 ± 4.74	1.98 ± 5.74
Winter	-0.66 ± 2.33	0.71 ± 3.21	-2.24 ± 4.10	-2.60 ± 1.87	-4.72 ± 2.57	-4.10 ± 3.10

Southern Pakistan

Region: FHS	A2			A1B		
	2020s	2050s	2080s	2020s	2050s	2080s
Annual	3.05 ± 5.12	6.40 ± 7.48	4.28 ± 9.46	-3.20 ±4.31	-0.32 ±5.53	-0.89 ±7.91
Summer	12.46 ± 9.77	42.19 ± 27.00	51.07 ± 39.78	11.21 ± 10.99	24.14 ± 18.06	37.57 ± 34.00
Winter	-7.53 ± 6.06	-12.90 ± 6.57	-20.51 ± 9.05	-16.13 ± 4.72	-9.92 ± 7.25	-15.10 ± 7.61

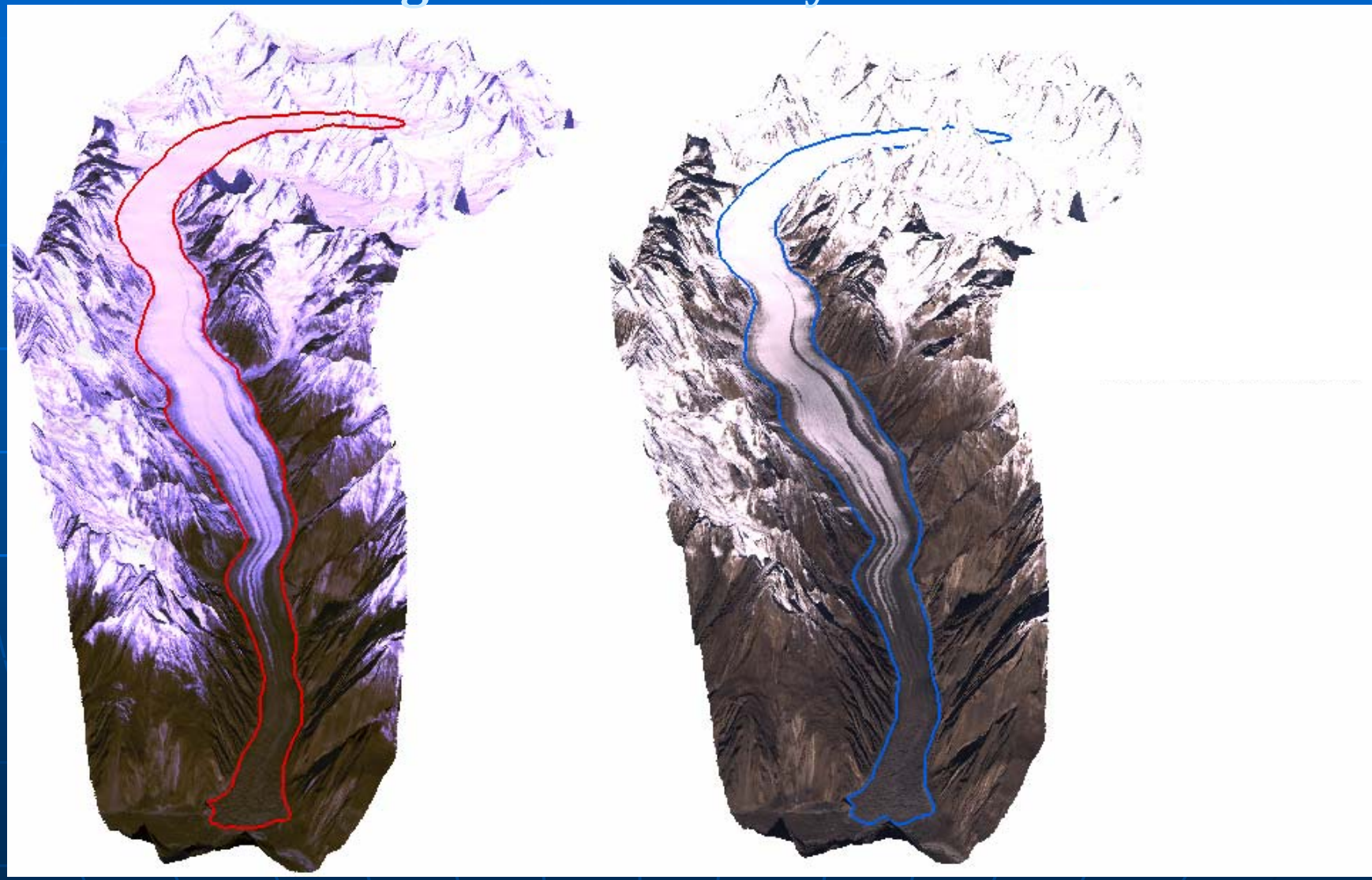
Projected Changes in Averarge Precipitation of Northern and Southern Pakistan

(Corresponding to IPCC A2 Scenario



Temporal Analysis of HKH Glacier

Comparative 3D View of Main Biafo Glacier with Overlaid Digitized Boundary of the Glacier



1992

2000

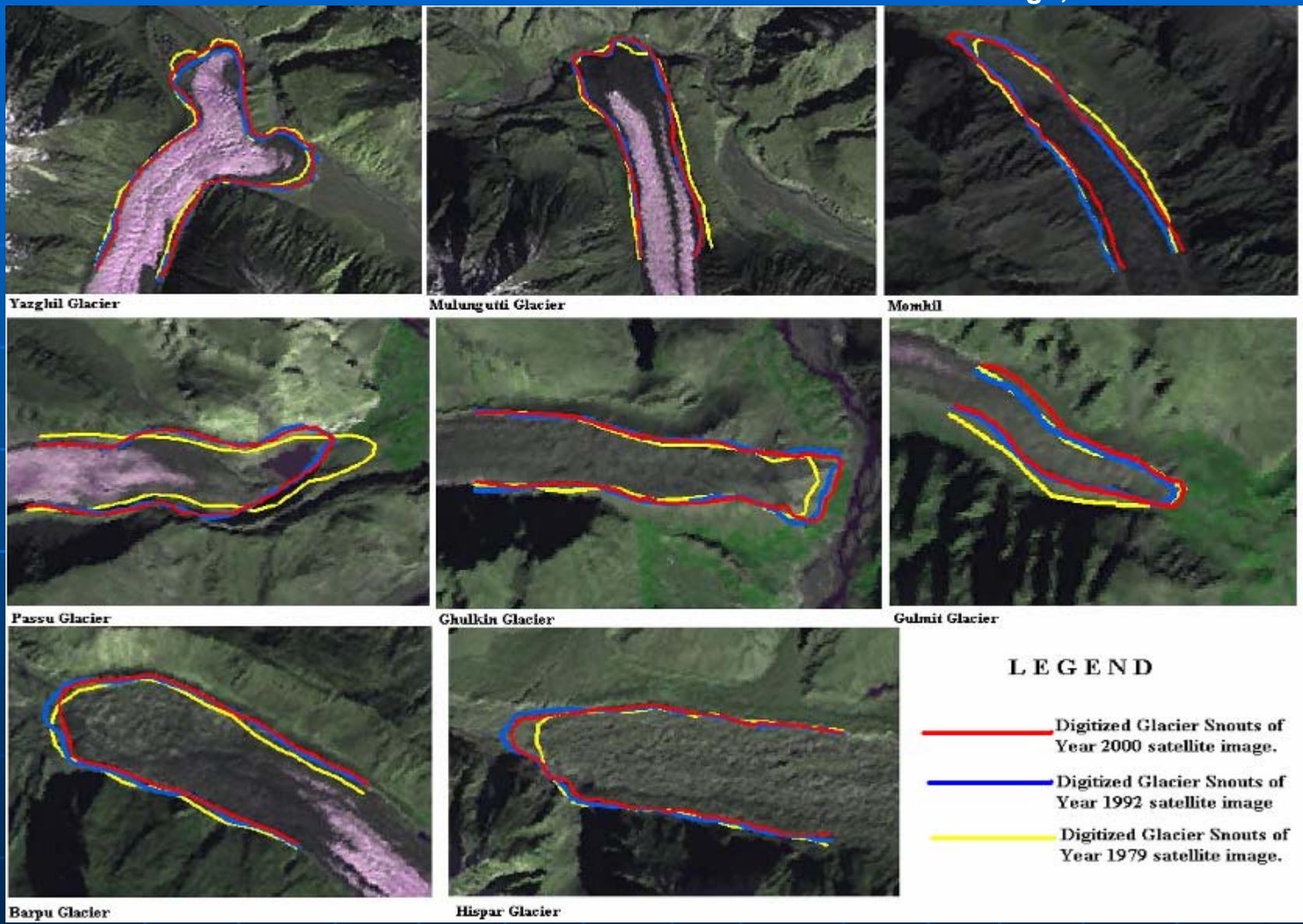
Observed Temporal Changes in Biafo Glacier, Central Karakoram, Northern Pakistan

Biafo Glacier	1992 A	2000 B	Change B-A	Remarks
Length (km)	60.212 ±0.030	60.020 ±0.030	-0.192 ±0.043	Significant Decrease (99% Certainty)
Area (km^2)	131.642 ± 1.806	133.159 ± 1.801	1.517 ±2.551	No Significant Change
Width (km) calculated as Area/ Length	2.186 ±0.030	2.219 ±0.030	0.033 ± 0.043	No Significant Change

Assuming that there are no significant measurement errors over and above those arising from the resolution of the satellite imagery, the following results were obtained:

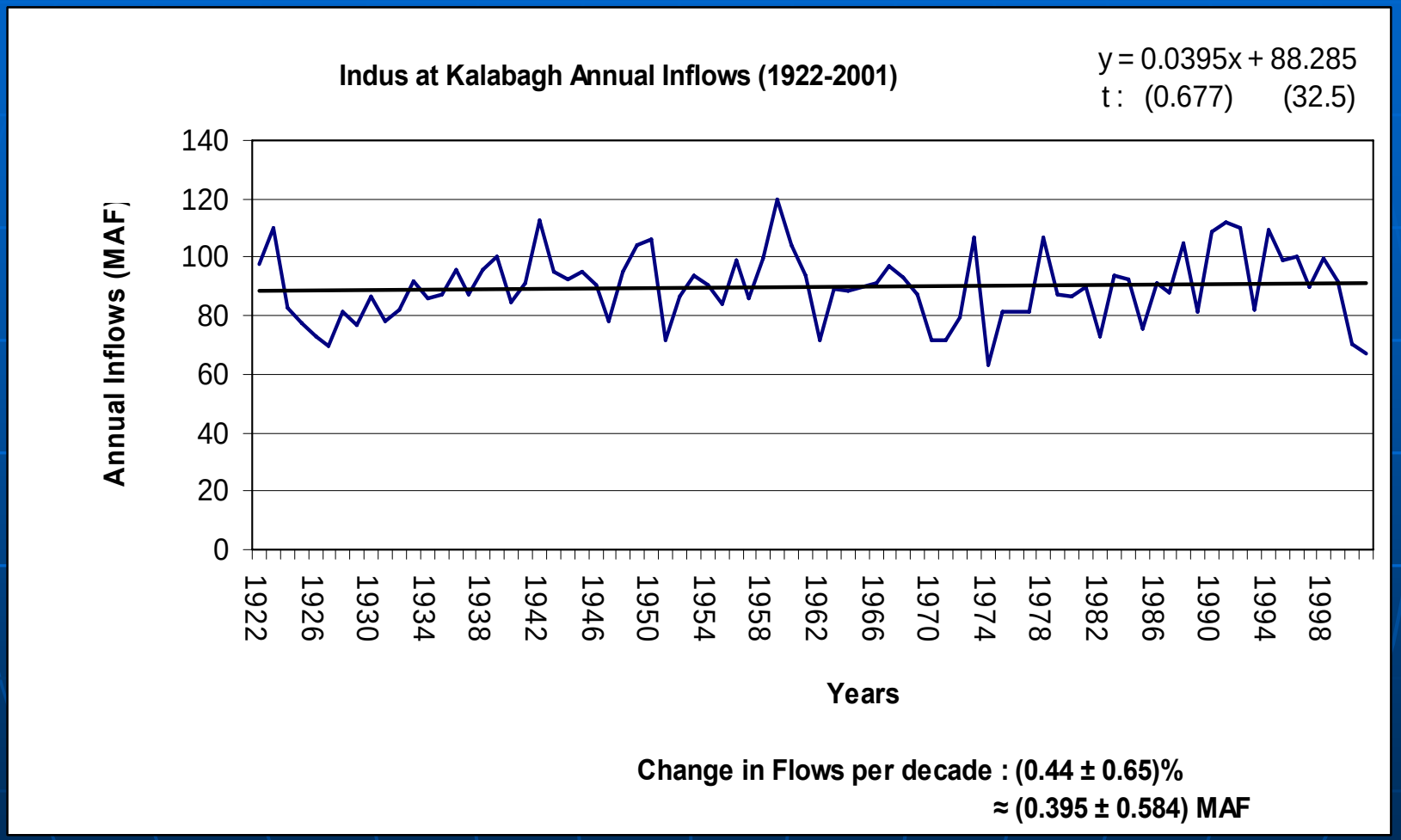
Pictorial View of the Digitized Snouts of Studied Glaciers of the Hunza River Basin, Northern Pakistan

Landsat image;Resolution 30m



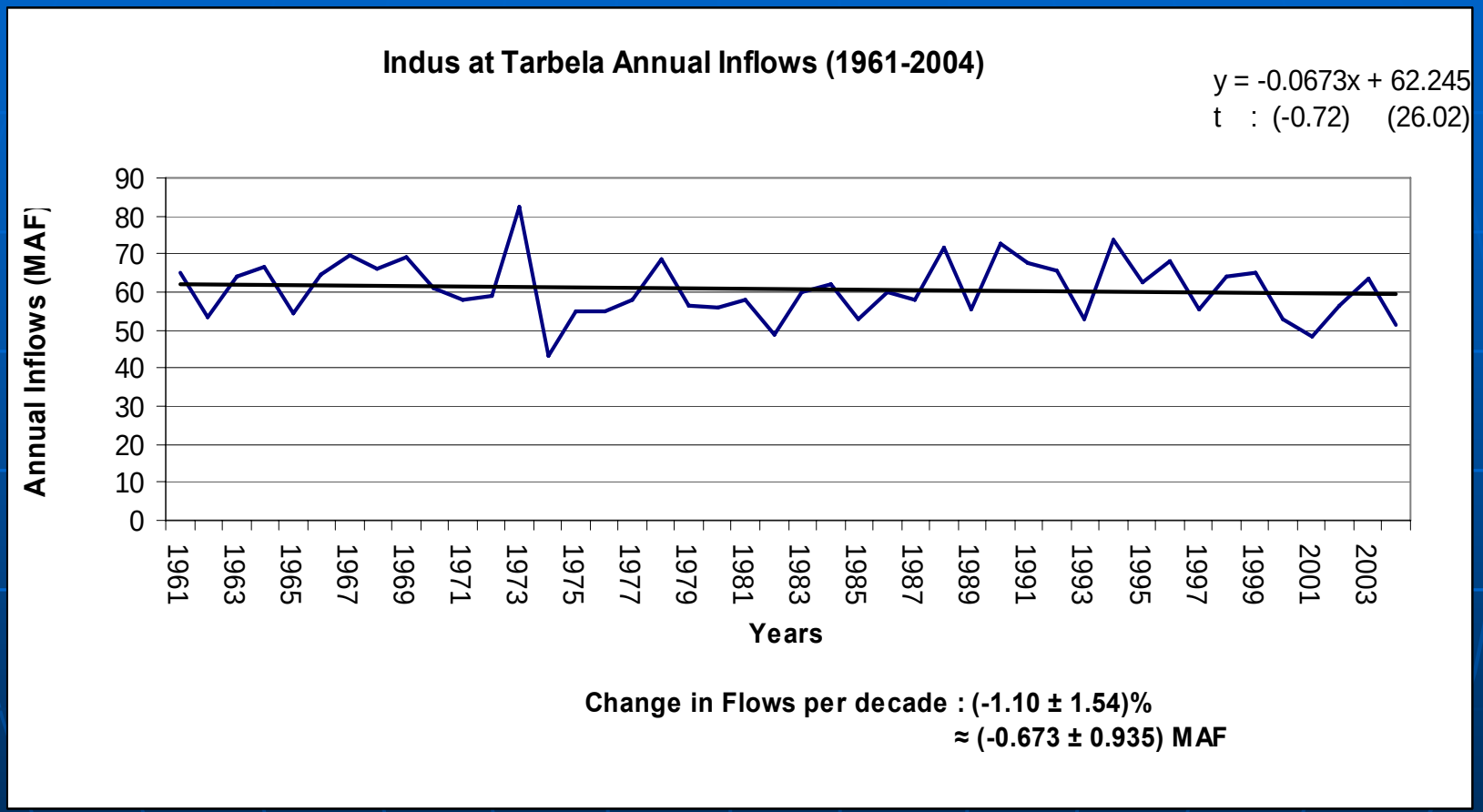
Trends of River Flows in the Upper Indus Basin

Trend in Annual inflows of Indus at Kalabagh



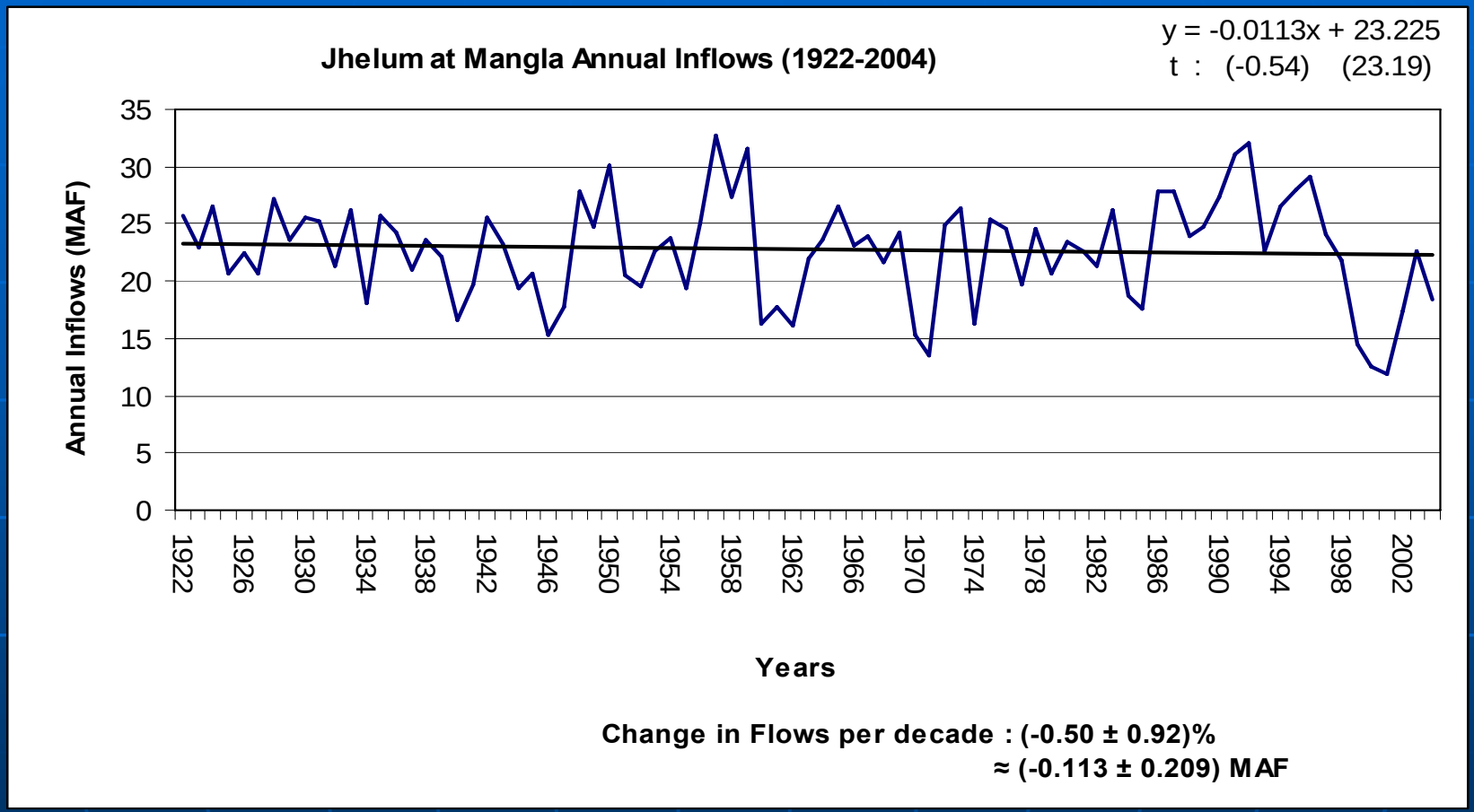
Data Source: Indus River System Authority (IRSA)

Trend in Annual inflows of Indus at Tarbela



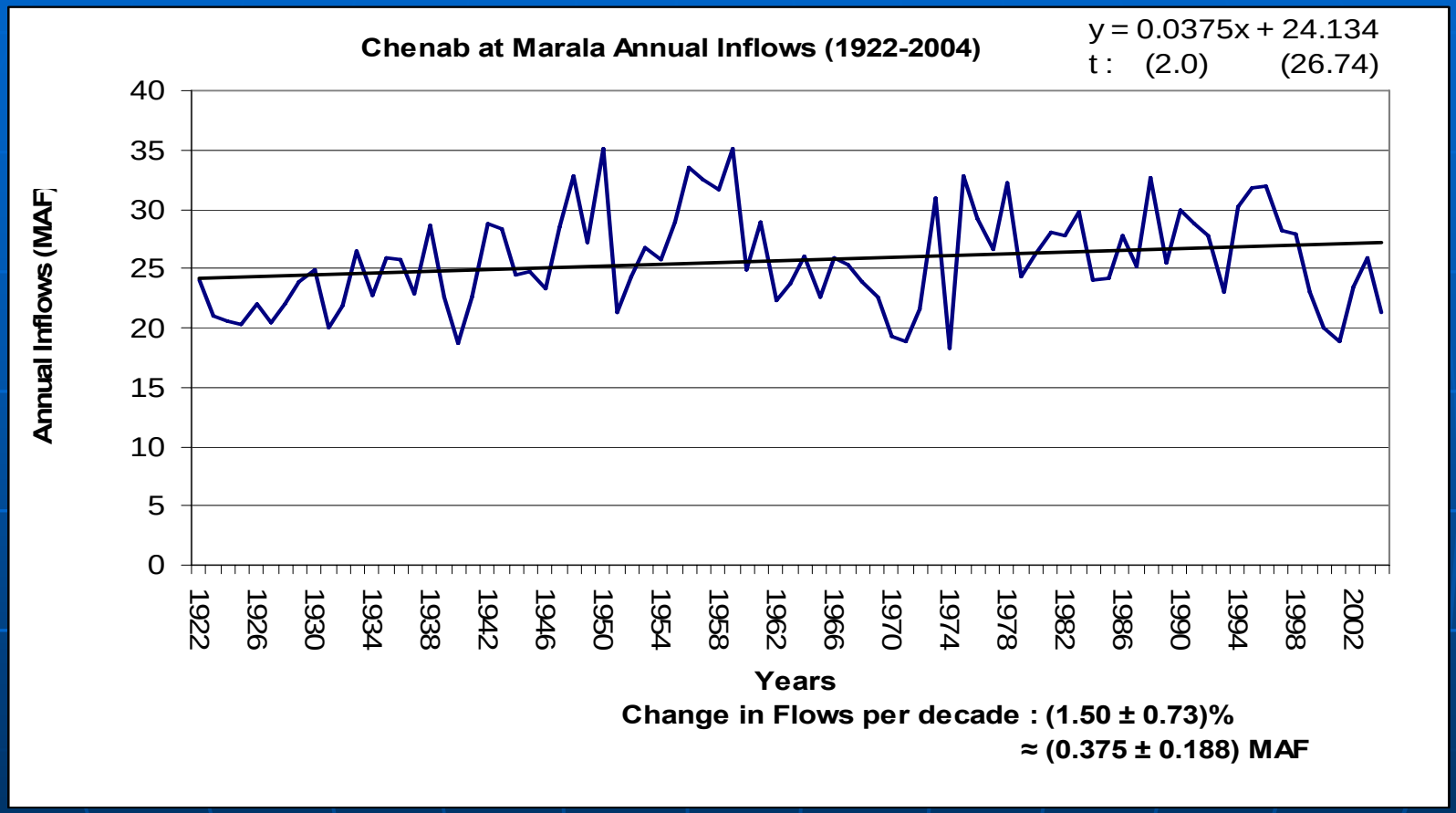
Data Source: Indus River System Authority (IRSA)

Trend in Annual inflows of Jhelum at Mangla



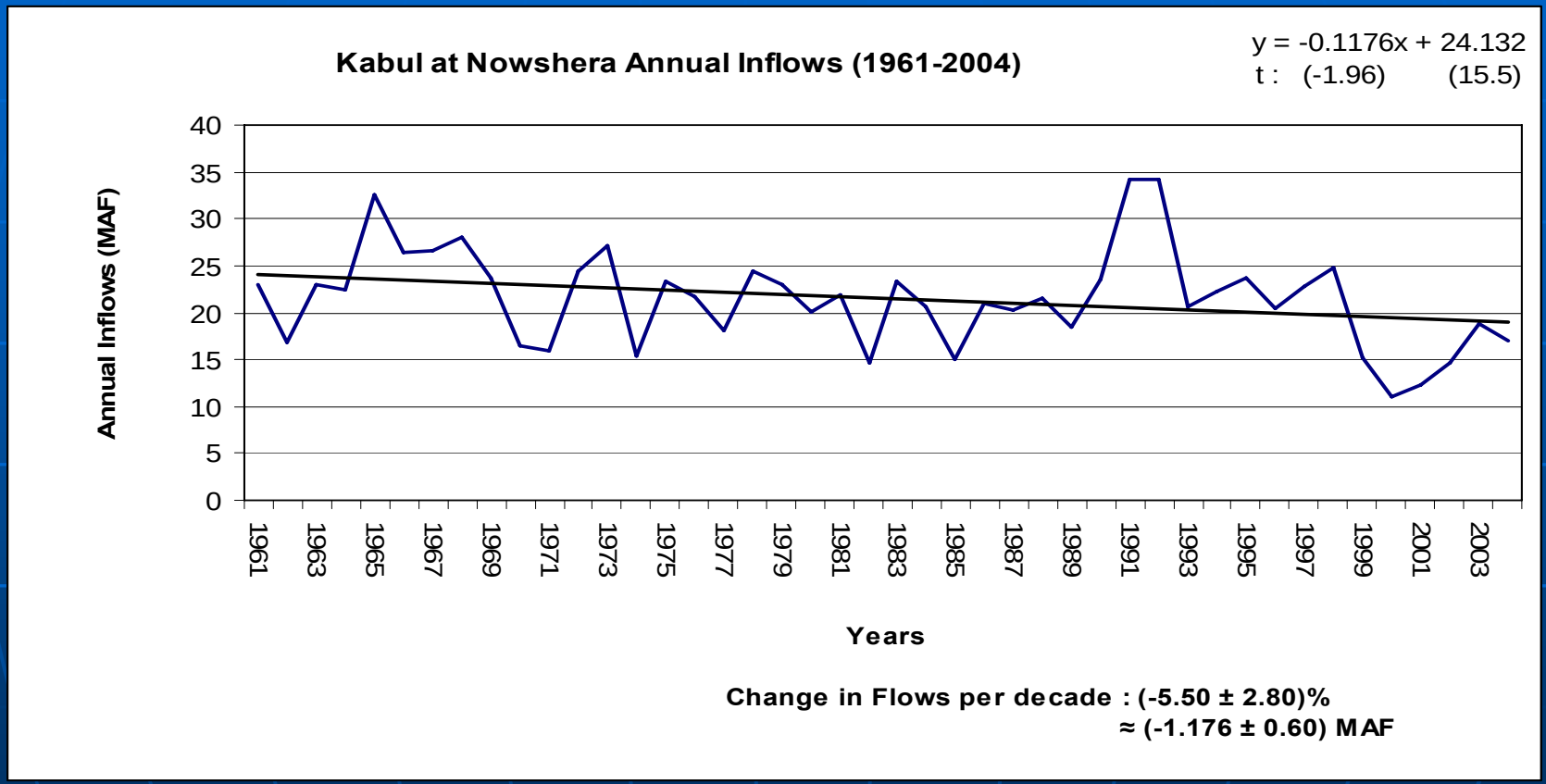
Data Source: Indus River System Authority (IRSA)

Trend in Annual inflows of Chenab at Marala



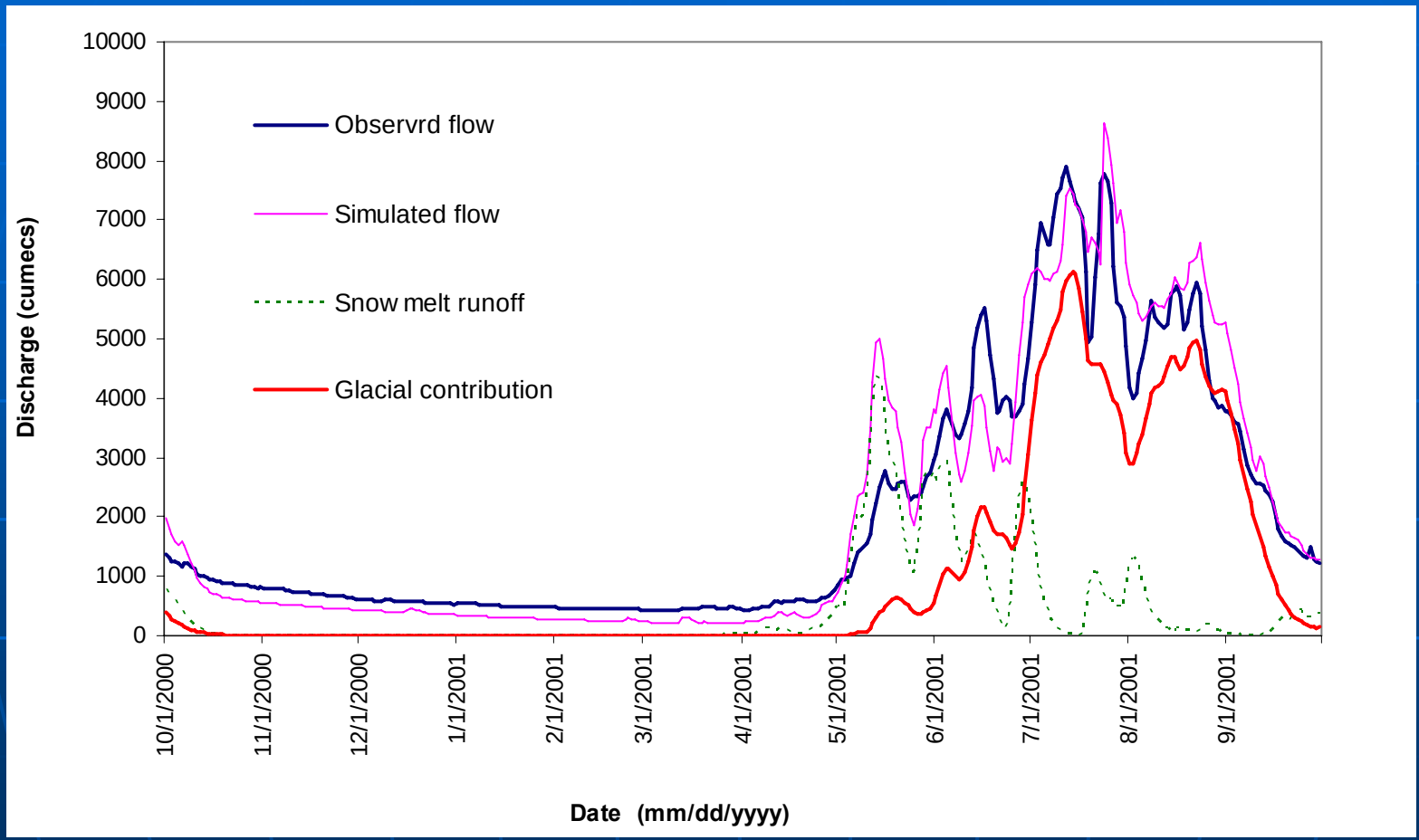
Data Source: Indus River System Authority (IRSA)

Trend in Annual inflows of Kabul at Nowshera



Data Source: Indus River System Authority (IRSA)

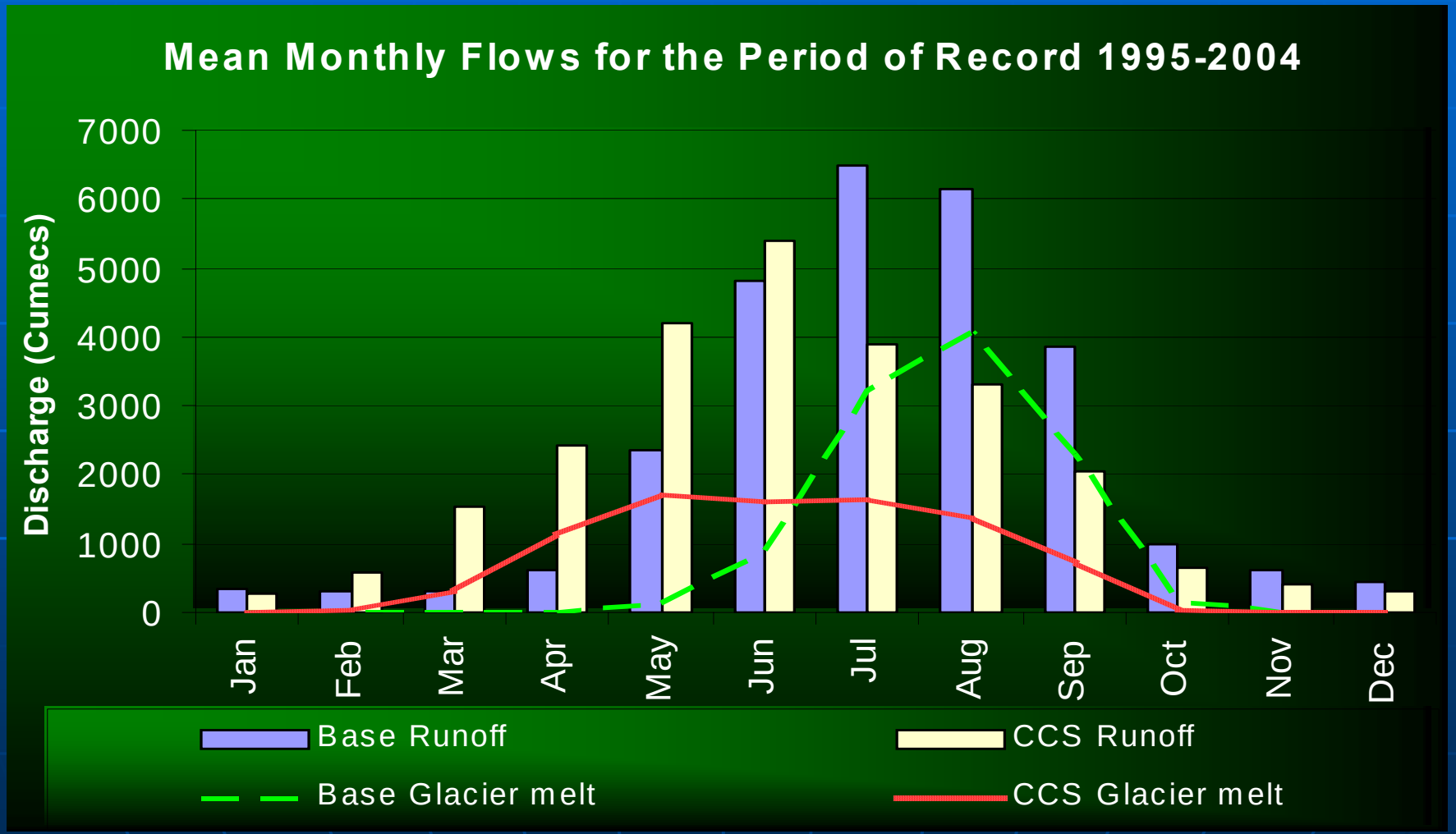
Indus River Flows at Bisham Qila Simulated by UBC Watershed Model



	R^2	Eff.	% Vol. Diff.
Calibration (1999-2004)	*0.87*	*0.86*	*0.32*
Validation (1995-1999)	*0.87*	*0.87*	*-5.16*

Impact of Climate Change and Glacier Retreat on UIB Flows

Assumed Climate Change Scenario (CCS):
Δ Temp: +3°C, Δ Glacier Area: - 50%



Main Results: 1. Annual flows reduced by 15%
2. Intra-Annual flow pattern considerably changed

Measures for Water Security

- Since an understanding of the response of Karakoram glaciers to climate change is very crucial for the assessment of Indus River flows, GCISC will work in collaboration with GLIMS, NASA and ICIMOD to establish the nature of temporal changes these glaciers have gone through during the last 2-3 decades

- At the same time GCISC will enhance its capacity to make use of UBC, DHSVM and other watershed models for making quantitative assessment of the changes in the pattern and amount of river flows resulting from glacier melting and changes in the climatic parameters.

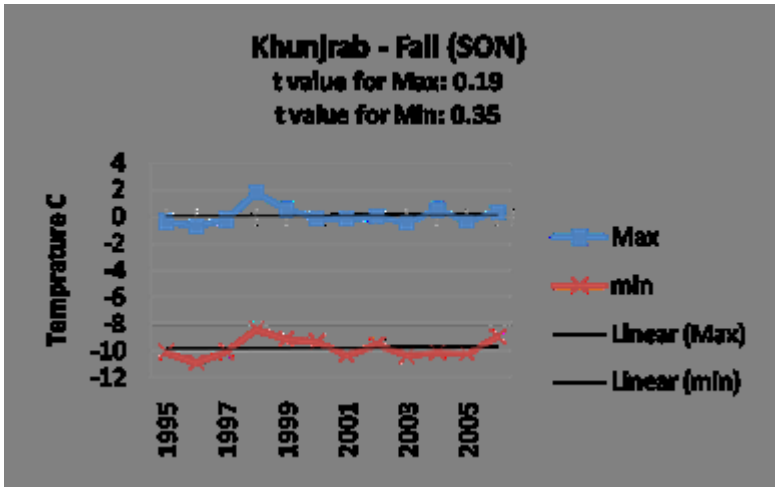
- Two important climate change related impacts are: (1) Increase in frequency and intensity of extreme precipitation events such as flood and droughts and (2) rise in sea level. Both these impacts call for increased reservoir capacity in order to provide regulated supplies of water for irrigation as well as for preventing increasing sea water intrusion.

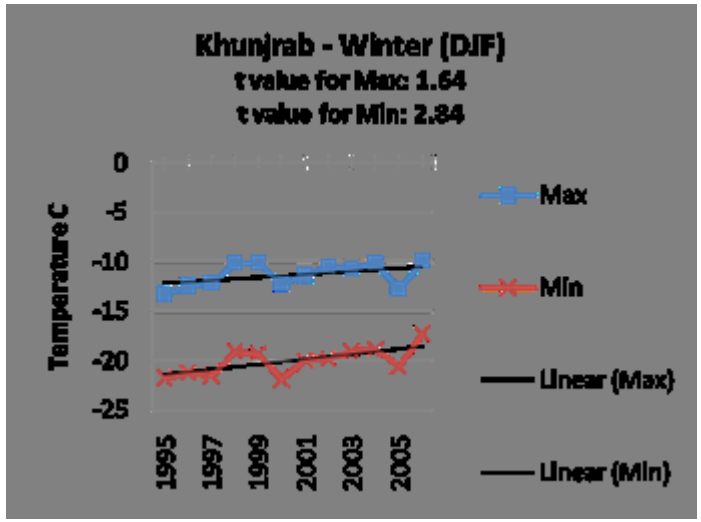
- In case the Karakoram glaciers are found to be receding, additional increased water reservoir capacity will be required in order to compensate for the loss of regulation by natural reservoirs (glaciers).

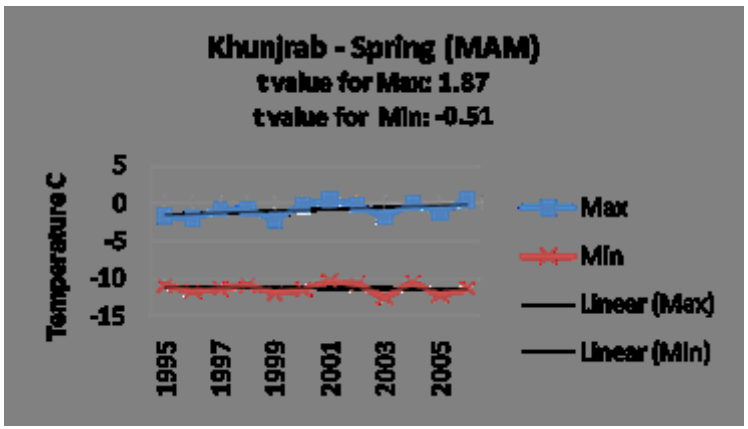
Concluding Remarks

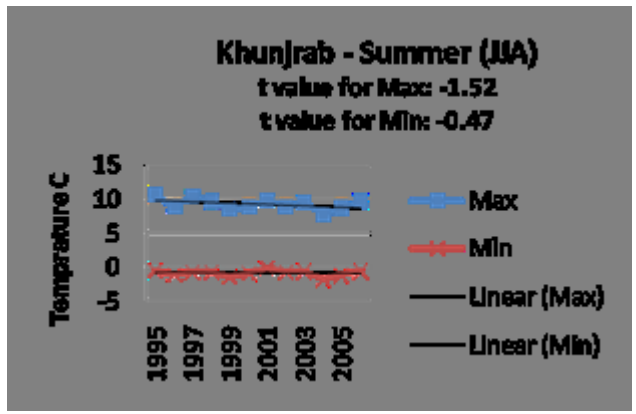
- Timely Response
- Study of Climate Change Impacts on Regional Basis
- Role of an Economist
- Effective Procedures to Dissemination of Research Results to Policy makers and Stake holders.

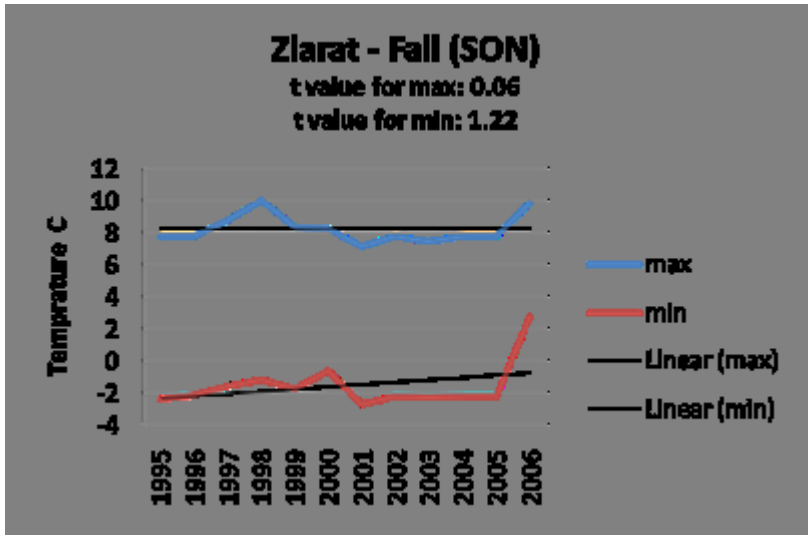
Searching Climate change Impact on Indus River Flows

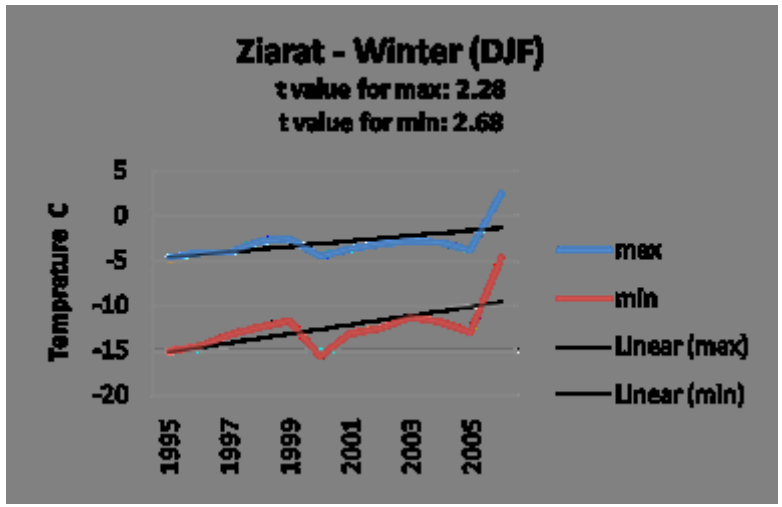

Khunjrab - Fall (SON)
t value for Max: 0.19
t value for Min: 0.35
Temprature C
4
2
0
-2
-4
-6
-8
-10
-12
1995
1997
1999
2001
2003
2005
Max
min
Linear (Max)
Linear (min)

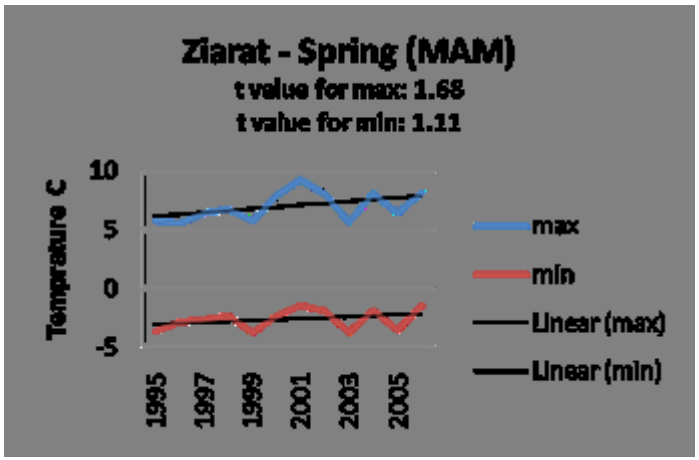

Khunjrab - Winter (DJF)
t value for Max: 1.64
t value for Min: 2.84
Temperature C
0
-5
-10
-15
-20
-25
1995
1997
1999
2001
2003
2005
Max
Min
Linear (Max)
Linear (Min)

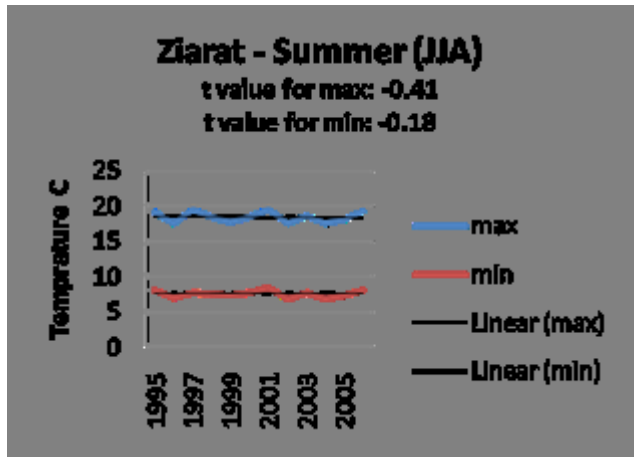

Khunjrab - Spring (MAM)
t value for Max: 1.87
t value for Min: -0.51
Temperature C
5
0
-5
-10
-15
1995
1997
1999
2001
2003
2005
Max
Min
Linear (Max)
Linear (Min)

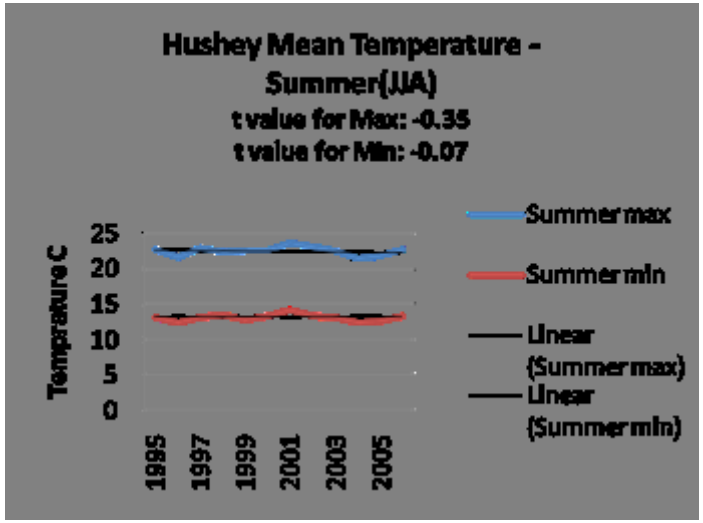

Khunjrab - Summer (JJA)
t value for Max: -1.52
t value for Min: -0.47
Temperature C
15
10
5
0
-5
1995
1997
1999
2001
2003
2005
Max
Min
Linear (Max)
Linear (Min)

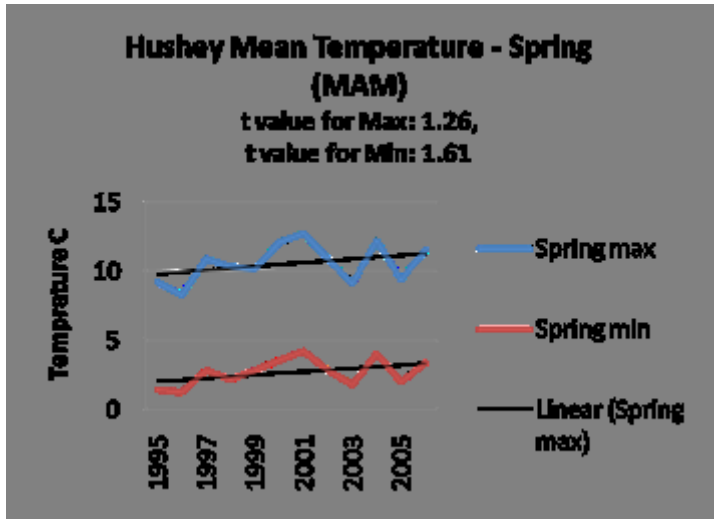

Ziarat - Fall (SON)
t value for max: 0.06
t value for min: 1.22
Temprature C
12
10
8
6
4
2
0
-2
-4
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
max
min
Linear (max)
Linear (min)

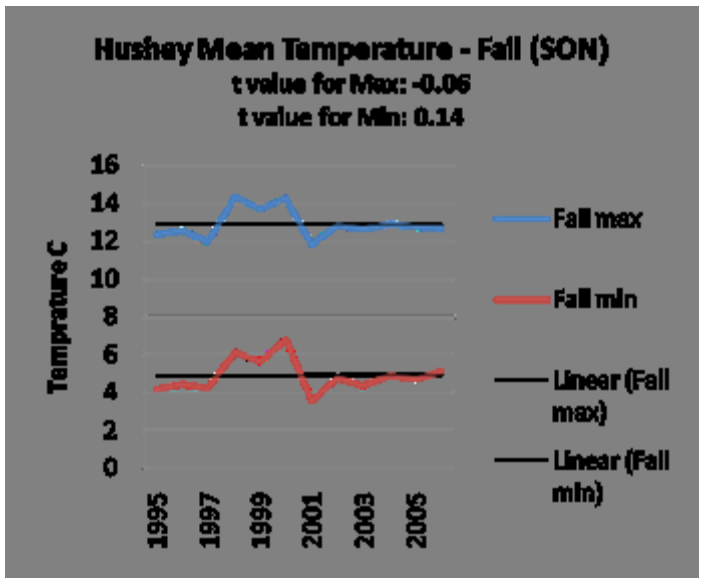

Ziarat - Winter (DJF)
t value for max: 2.28
t value for min: 2.68
Temprature C
5
0
-5
-10
-15
-20
1995
1997
1999
2001
2003
2005
max
min
Linear (max)
Linear (min)

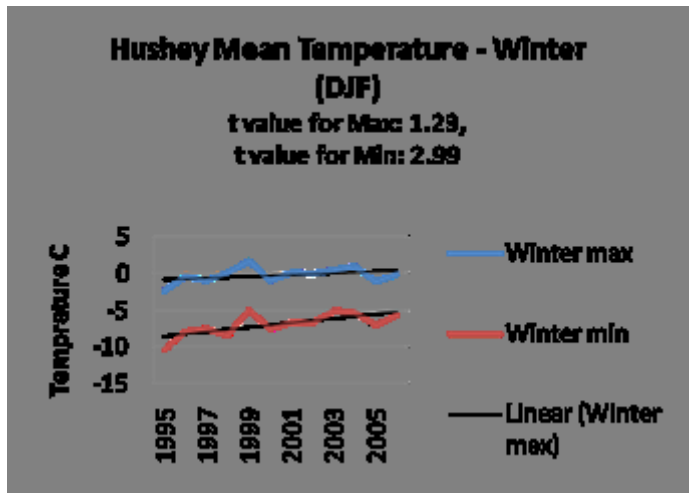

Ziarat - Spring (MAM)
t value for max: 1.68
t value for min: 1.11
Temprature C
10
5
0
-5
1995
1997
1999
2001
2003
2005
max
min
Linear (max)
Linear (min)


Ziarat - Summer (JJA)
t value for max: -0.41
t value for min: -0.18
Temprature C
25
20
15
10
5
0
1995
1997
1999
2001
2003
2005
max
min
Linear (max)
Linear (min)


Hushey Mean Temperature - Summer(JJA)
t value for Max: -0.35
t value for Min: -0.07
Temprature C
25
20
15
10
5
0
1995
1997
1999
2001
2003
2005
Summer max
Summer min
Linear (Summer max)
Linear (Summer min)


Hushey Mean Temperature - Spring (MAM)
t value for Max: 1.26,
t value for Min: 1.61
Temprature C
15
10
5
0
1995
1997
1999
2001
2003
2005
Spring max
Spring min
Linear (Spring max)


Hushey Mean Temperature - Fall (SON)
t value for Max: -0.06
t value for Min: 0.14
Temprature C
16
14
12
10
8
6
4
2
0
1995
1997
1999
2001
2003
2005
Fall max
Fall min
Linear (Fall max)
Linear (Fall min)


Hushey Mean Temperature - Winter (DJF)
t value for Max: 1.29,
t value for Min: 2.99
Temprature C
5
0
-5
-10
-15
1995
1997
1999
2001
2003
2005
Winter max
Winter min
Linear (Winter max)

Climate Change – A Reality

- There is now a consensus among the scientific community that Global Warming has occurred due to human induced anthropogenic activities (mainly due to burning of fossil fuel).
- The Global Warming is causing :
  - Accelerated Rate of Snow and Glacier Melt
  - Sea level Rise
  - Intense Rain Storms
  - Floods and Droughts
  - Heat and Cold Waves
  - Loss of Biodiversity
- The increased intensity & frequency of extreme climate events linked to global warming will cause large scale disasters.