STUDIES OF HIMALAYAN GLACIER AND SEASONAL SNOW AS SIGNATURE OF CLIMATE CHANGE

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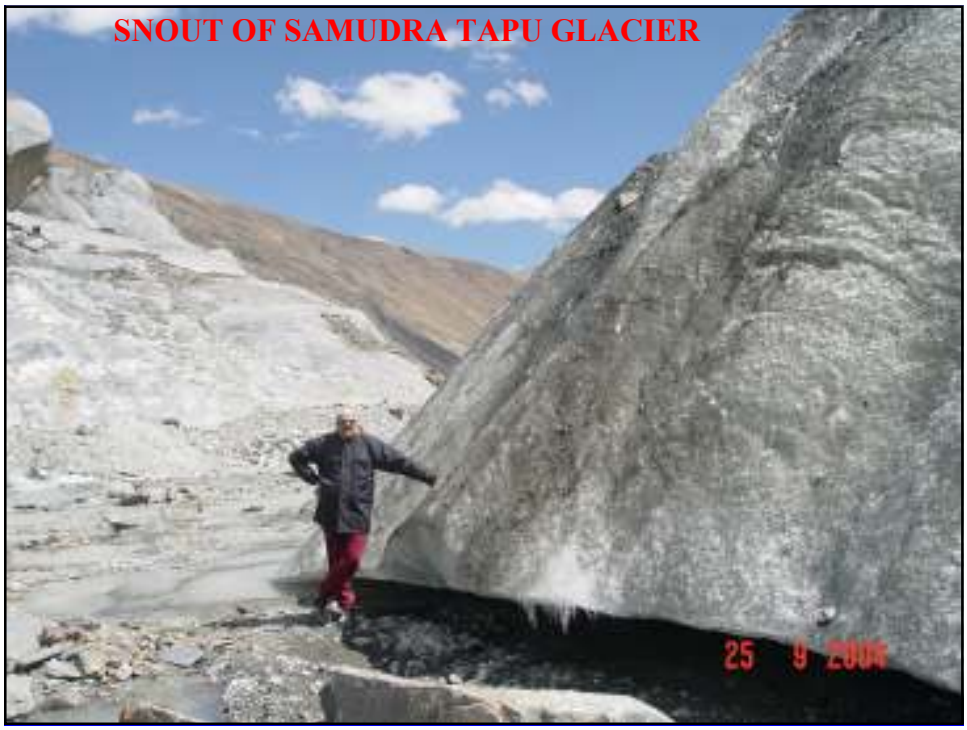
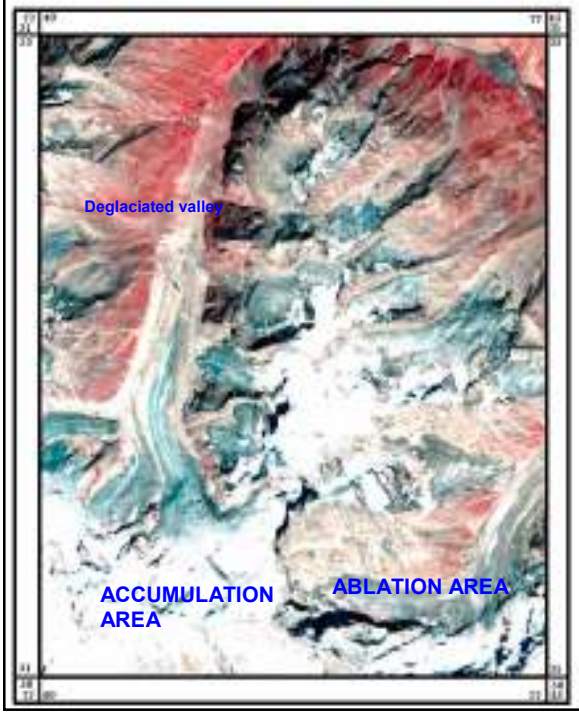
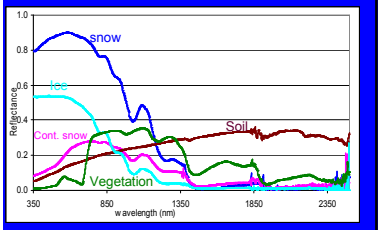


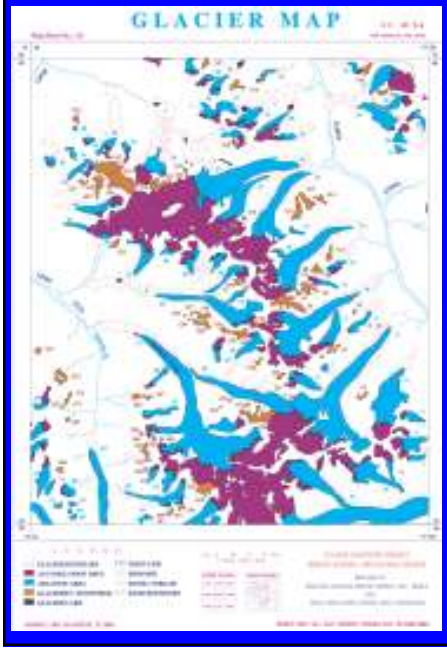


GLACIER FEATURES FALSE COLOUR COMPOSITE OF LISS-IV IMAGERY OF RESOURCESAT SEPTEMBER 2004



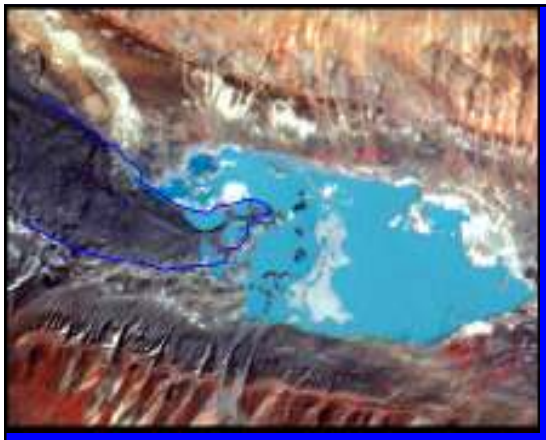
REFLECTANCE IN HIMALAYA

Glacier Inventory



Basin	Year of mapping	Number of glaciers, glacieret and snowfield	Areal extent (sq km)
Satluj (H.P.)	1993	2322	2697
Tista (Sikkim)	1997	284	692
Dhauli Ganga (Uttarakhand)	1996	108	229
Chenab (H.P.)	2001	1186	1420
Total	-----	3900	5038

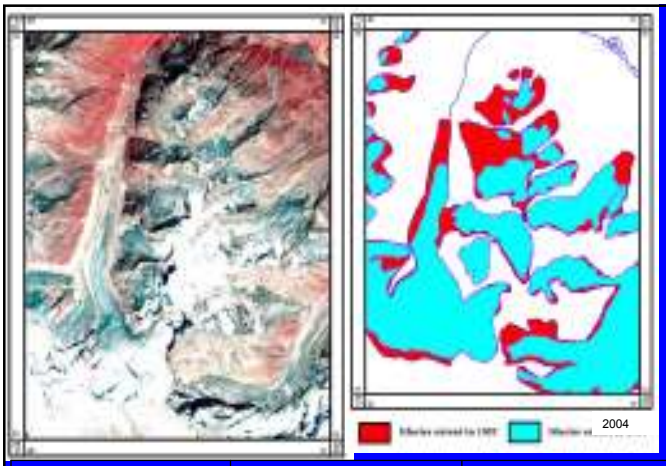
Basin	Scale	Year of mapping	Glacier number	Areal extent (sq km)
Indian Himalaya	250000	1988	1702	23,300



RETREAT OF SAMUDRA TAPU GLACIER

LISS-IV 2006

Year	Glacier Area (sq.km)	Glacier Length (m)	Loss in Length (m)	Retreat rate (m/y)
1962	73.0	17851	-	
1993	-	17200	650	21
2000	65.0	17113	87	12
2006	64.93	16957	156	26



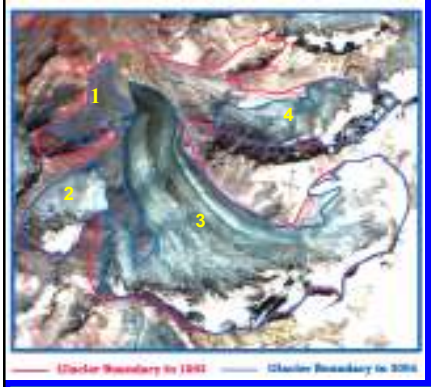
GLACIAL RETREAT

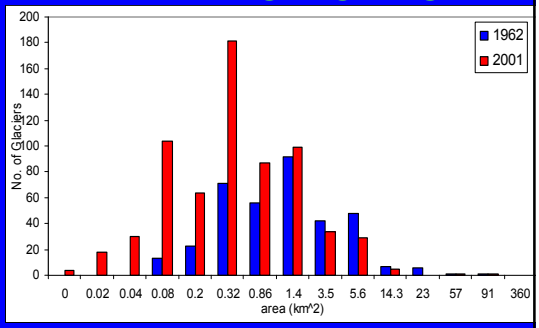
IRS LISS-IV SATELLITE IMAGERY OF 5.8 M SPATIAL RESOLUTION IN PARBATI RIVER BASIN.

LOSS IN GLACIAL AREA BETWEEN 1962 AND 2004

Name of basin	Glacier numbers	Glacier Area (km^2)		
		1962	2001/2/4	Loss %
Chenab	359	1414	1110	21
Parbati	88	488	379	22
Baspa	19	173	140	19
Warwan	253	847	672	21
Bhut	189	469	420	10
Total	908	3391	2721	20

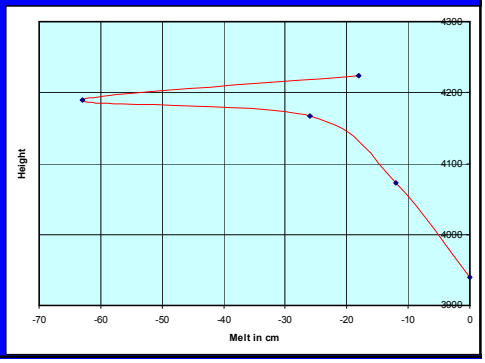
FRAGMENTATION OF HIMALAYAN GLACIERS





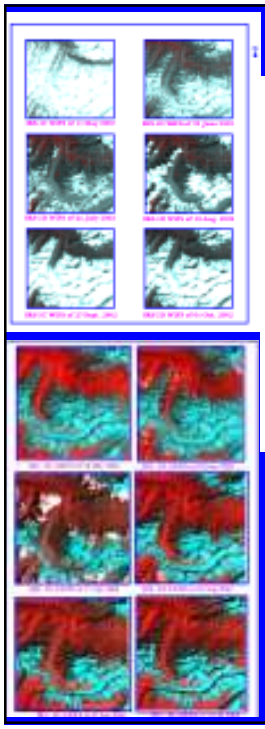
Fragmentation will have profound impact on glacial retreat. It effectively reduces depth, response time and accelerates retreat.

Ice melt near Gomukh, Gangotri glacier. Less melt near Gomukh. (Source: Maruthi et.al., 2003)

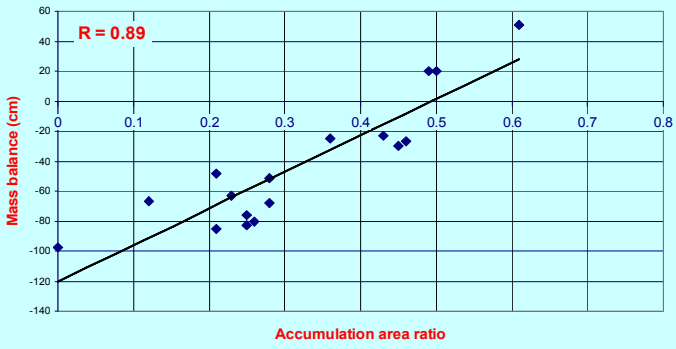


INFLUENCE OF GLACIAL SIZE ON RETREAT: CHENAB

Glacier Area (km²)	Number of glaciers 1962	Glacier Area (km²)		Change in %
		1962	2001	
< 1	127	68	42	**38**
1-5	159	382	269	29
5-10	48	329	240	27
> 10	25	635	559	12
Total	359	1414	1110	21



MASS BALANCE: BASPA BASIN



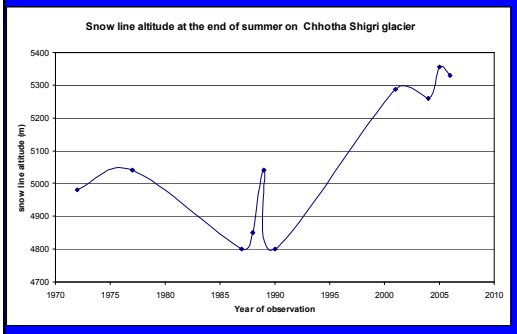
GLACIERS ZERO AAR: BHAGA: 18 CHANDRA: 4 BASPA 4

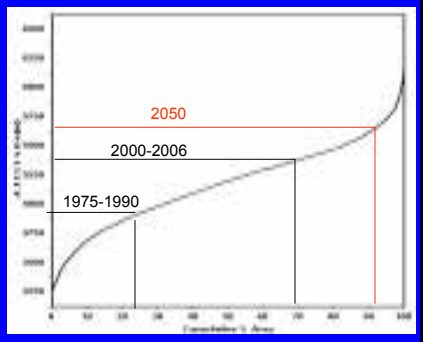
MEAN SP. MASS BALANCE: 19 GLACIRS BASPA BASIN

2001: - 40 cm 2002: -78 cm 2004: -57 cm

Loss of glacial ice: 0.11735 cu km/year

PRESENT AND FUTURE ALTITUDE OFSNOW LINE





Cumulative per cent area below Altitude zones for 30 glaciers in Baspa basin. ELA in Baspa basin 5300 m. Loss in glacier area between 1961-2001 is 19 %. Max. glacial altitude is less than ELA.

MODELING GLACIAL CHANGES: PARBATI GLACIER

	Main glacial body
Areal extent of glacier in 2001	23.7 km^2
Accumulation area in 2001	3.56 km^2
Accumulation Area Ratio in 2001	0.138
Estimated glacial mass balance 2001	-86 cm
Estimated depth of glacier in 2001	126 m
Measured rate of melting at snout (Chhota Shigri glacier 1988-89)	-6 m/year
Measured glacier length in 2001	10120 m
Estimated response time for loss in length from 2001	21 years
Estimated loss in glacial length from 2001 to 2022 Measured loss in glacial length from 2001 to 2006	1461 m (69 m/y) 206 m (41 m/y)

Model parameters: Mass balance, ELA, rate of melting at terminus, present glacier length and glacier depth.

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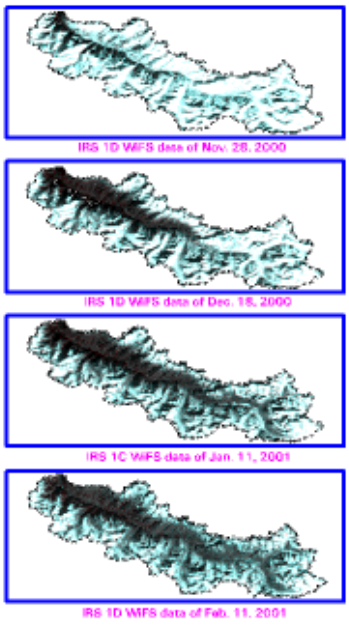
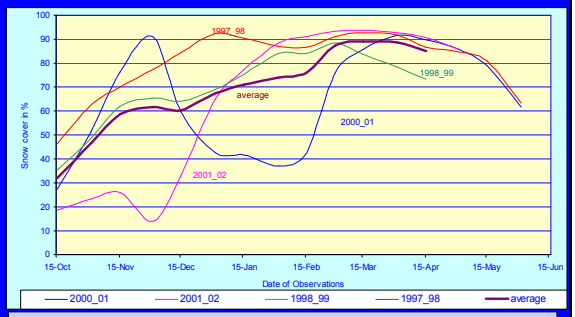
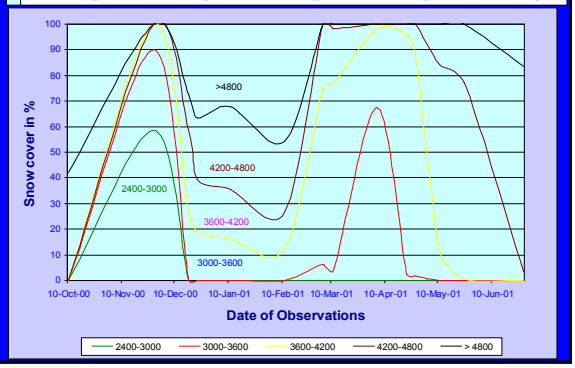
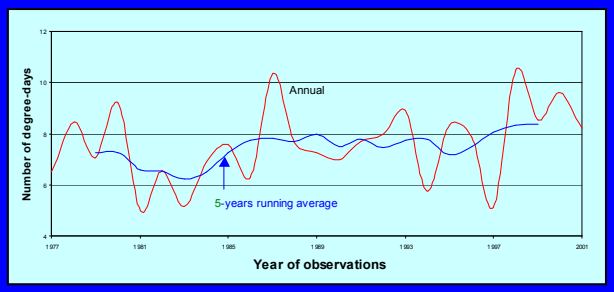
EFFECT OF CLIMATIC VARIATIONS ON SNOW MELT

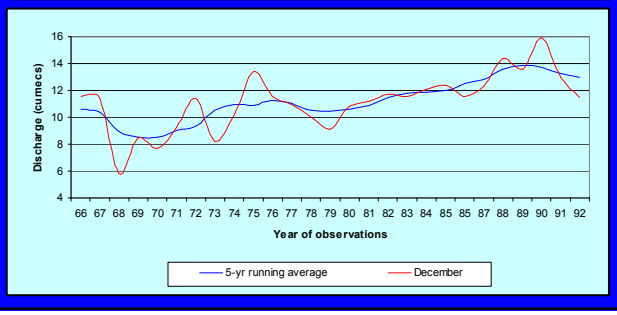




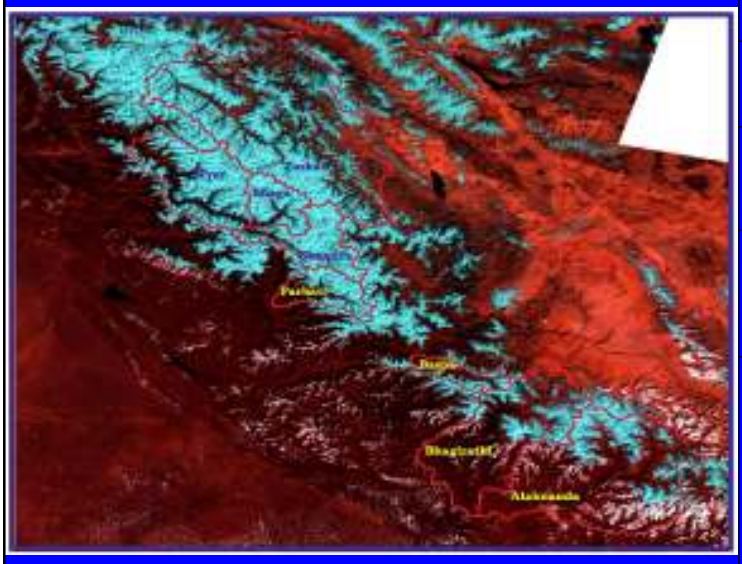


EFFECT OF CLIMATIC VARIATION ON RUNOFF OF THE BASPA RIVER





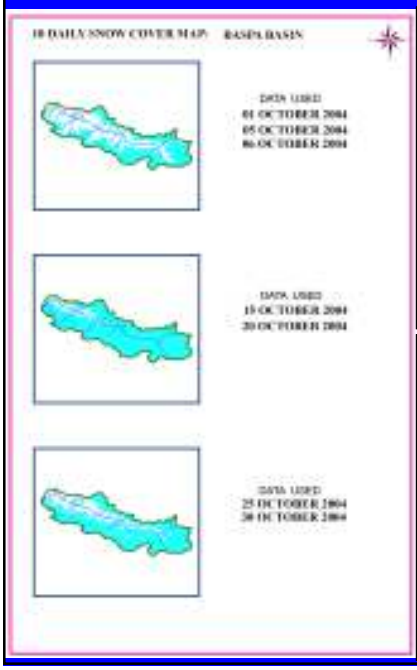
MONITORING OF SEASONAL SNOW USING AWiFS DATA

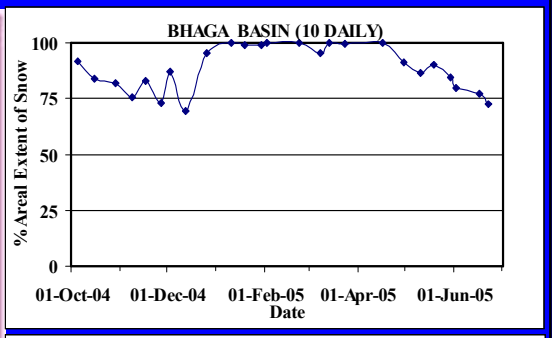


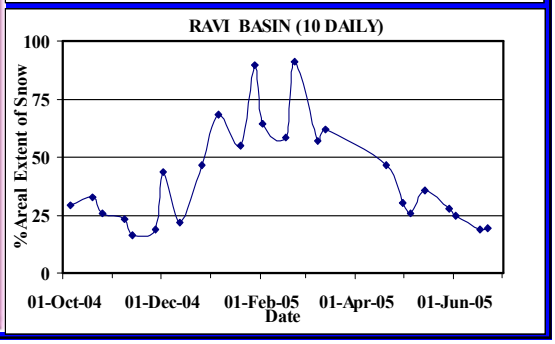
28 SUB BASINS ARE BEING MONITORED FROM YEAR 2004 AND 5

Basin	Sub-basins
Ganga	Alaknanda, Bhagirathi, Yamuna
Satluj	Spiti, Pin, Baspa, Jiwa, Parbati, Beas
Chenab	Ravi, Chandra, Bhaga, Miyar, Bhut, Warwan
Indus	Jhelum, Kishanganga Astor, Suru, Dras, Shigo, Zaskar Nubra, Shyok, Hanza, Gilgit, Shasgan, Shigar

ABLATION PATTERN OF SEASONAL SNOW COVER







SEASONAL SNOW AND GLACIER MELT RUNOFF MODELING

(Pre-feasibility investigation, Autumn, winter, summer, Monsoon)

$$Q=c\{a(T*G)\}+c\{S*W)-(M*Sw)\} + (c*P*B)$$

Where,

- **Q = Average seasonal runoff (cu m/s)**
- **C = Runoff coefficient**
- **a = Melt factor (cm/degree C.d)**
- **T = Average seasonal degree-day (degree.day)**
- **G = Area of snow and glaciers (sq km)**
- **S = Area of seasonal snow (sq km)**
- **W = Water equivalent of winter snow fall (m)**
- **M = Winter snow melt (m)**
- **Sw= Snow cover in winter**
- **P = Average seasonal rainfall (m)**
- **B = Basin area without snow/glacier (sq m)**

Comparison: Model and Field runoff

Developed: Malana Validated: Tosh Used: Sorang

Season	Malana Runoff (cumecs)		Error %	Tosh Runoff (cumecs)		Error %	Model runoff Sorang (cumecs) (Kirang Khad)
	Model	Field		Model	Field		
Autumn	10.22	9.94	2.8	16.49	16.61	0.7	4.40 (8.2)
Winter	3.85	4.06	3.0	5.30	5.69	8.0	1.69 (1.8)
Summer	9.95	11.06	10.0	21.08	23.23	10.0	6.52 (10.8)
Monsoon	23.05	28.36	18.7	49.13	61.62	25.0	19.65 (27.4)

Estimated seasonal runoff (cumecs) in Wangar Gad basin

Season	2004	2040	Change in Runoff	%Change in Runoff
Autumn	9.6	7.6	2.0	20.5
Winter	4.1	3.3	0.8	18.7
Summer	15.9	14.6	1.3	8.4
Monsoon	22.4	16.1	6.3	28.0

SALIENT OBSERVATIONS

- Glacial retreat in Chenab, Parbati and Baspa basins suggests an overall reduction in glacier area by 21 %.
- Mean of glacial extent reduced from 1.4 to 0.32 sq km. 38 % retreat of small glacieretes and ice fields of size less than 1 sq km. Number of glaciers increased due to fragmentation but extent is reduced.
- Snow line at the end of ablation season changed from 4900 m to 5300 m since 1970. Many glaciers are having no accumulation area and these will experience terminal retreat due to lack of formation of new ice.
- Large scale melting and retreat of seasonal snow was observed in basins like Ravi throughout the winter. In high altitude basins like Baspa and Bhaga, large scale retreat was observed in beginning of winter.
- Average stream runoff of Baspa river in December was increased by 75 per cent from 1970.
- These observations suggests an influence of climate change on the Himalayan cryosphere. This will affect future availabity of water resources. Our model suggests reduction in stream runoff of Wagar gad, Himachal Pradesh by 8 to 28 % by year 2040, depending on season.

THANK YOU