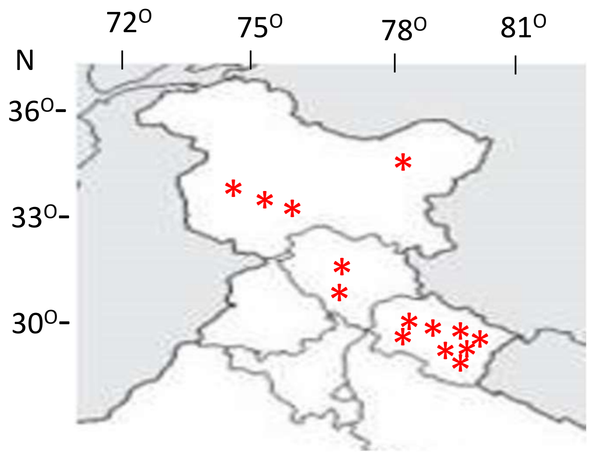
Observed climate change in the Himalayas

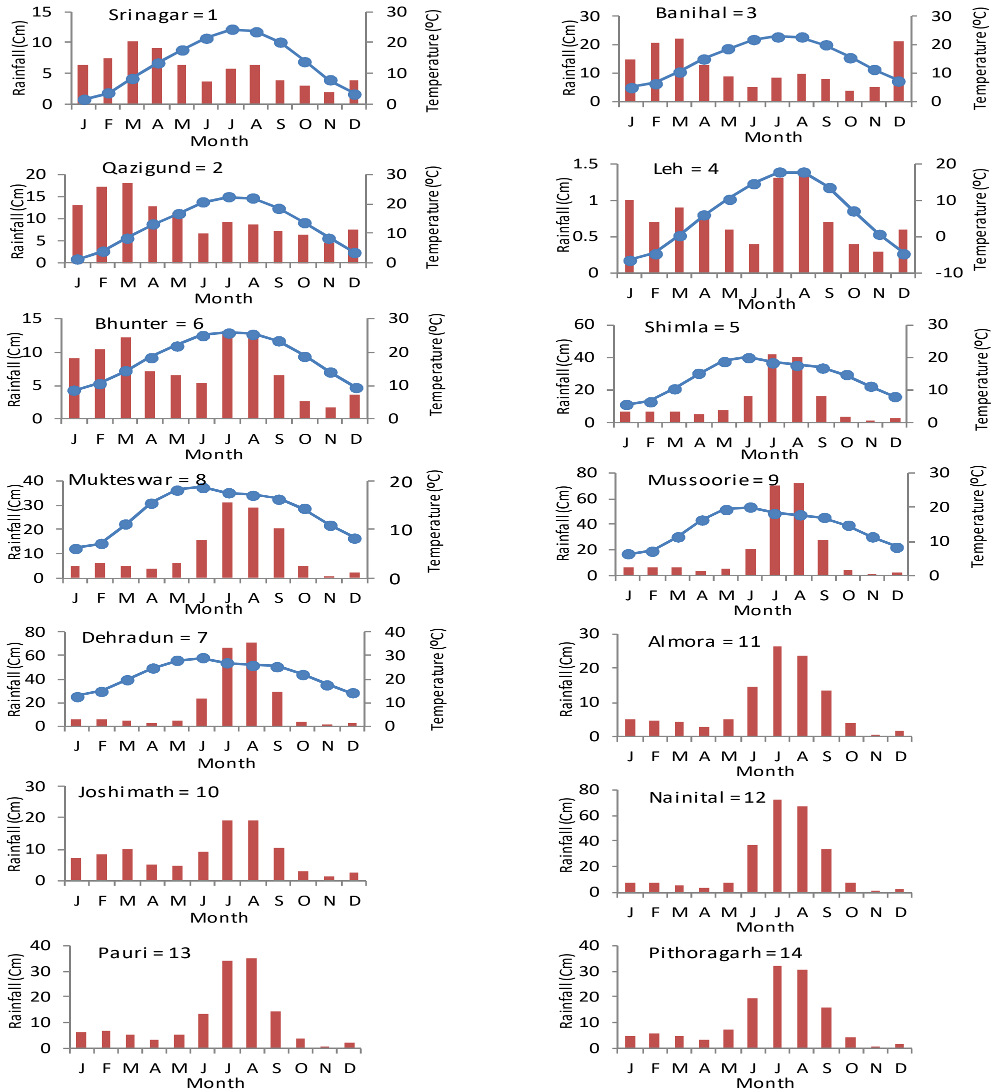
Hemant Borgaonkar, IITM

Science and Training Workshop on Climate Change over the High Mountains of Asia during 9 -12 October, 2018, IITM, Pune

- Temperature analysis ……trends
- Rainfall analysis…………….trends
- Dendroclimatic reconstructions over the Himalayan region



Sr. No.	Station	State	Lat.	Long.	Alti. (M)	Temperature	Rainfall
1	Srinagar	J&K	34^0 05’	74^0 50’	1587	1901-2016	1892-2016
2	Quazigund	J&K	33^0 30’	75^0 10’	1630	1962-2016	1962-2016
3	Banihal	J&K	33^0 35’	75^0 05’	1690	1962-2016	1962-2016
4	Leh	J&K	34^0 09’	77^0 34’	3506	1901-1990	1876-1990
5	Shimla	H.P.	31^0 06’	77^0 10’	2202	1901-2007	1863-2007
6	Bhunter	H.P.	31^0 50’	77^0 10’	1067	1964-2014	1964-2014
7	Dehra Dun	U.K.	30^0 19’	78^0 02’	682	1901-2015	1863-2007
8	Mukteswar	U.K	29^0 28’	79^0 39’	2311	1901-2014	1964-2014
9	Mussoorie	U.K.	30^0 27’	78^0 05’	2042	1901-1990	1863-2007
10	Joshimath	U.K.	30^0 33’	79^0 34’	2045	----	1871-1987
11	Almora	U.K.	29^0 30’	79^0 35’	1642	----	1856-1978
12	Nainital	U.K.	29^0 25’	79^0 27’	2084	----	1849-1978
13	Pauri	U.K.	30^0 07’	78^0 44’	1824	----	1871-1978
14	Pithoragarh	U.K.	$30^0$01’	80^0 14’	1514	----	1864-1978



Monthly variations of rainfall and temperature of western Himalayan stations based on long-term averages.

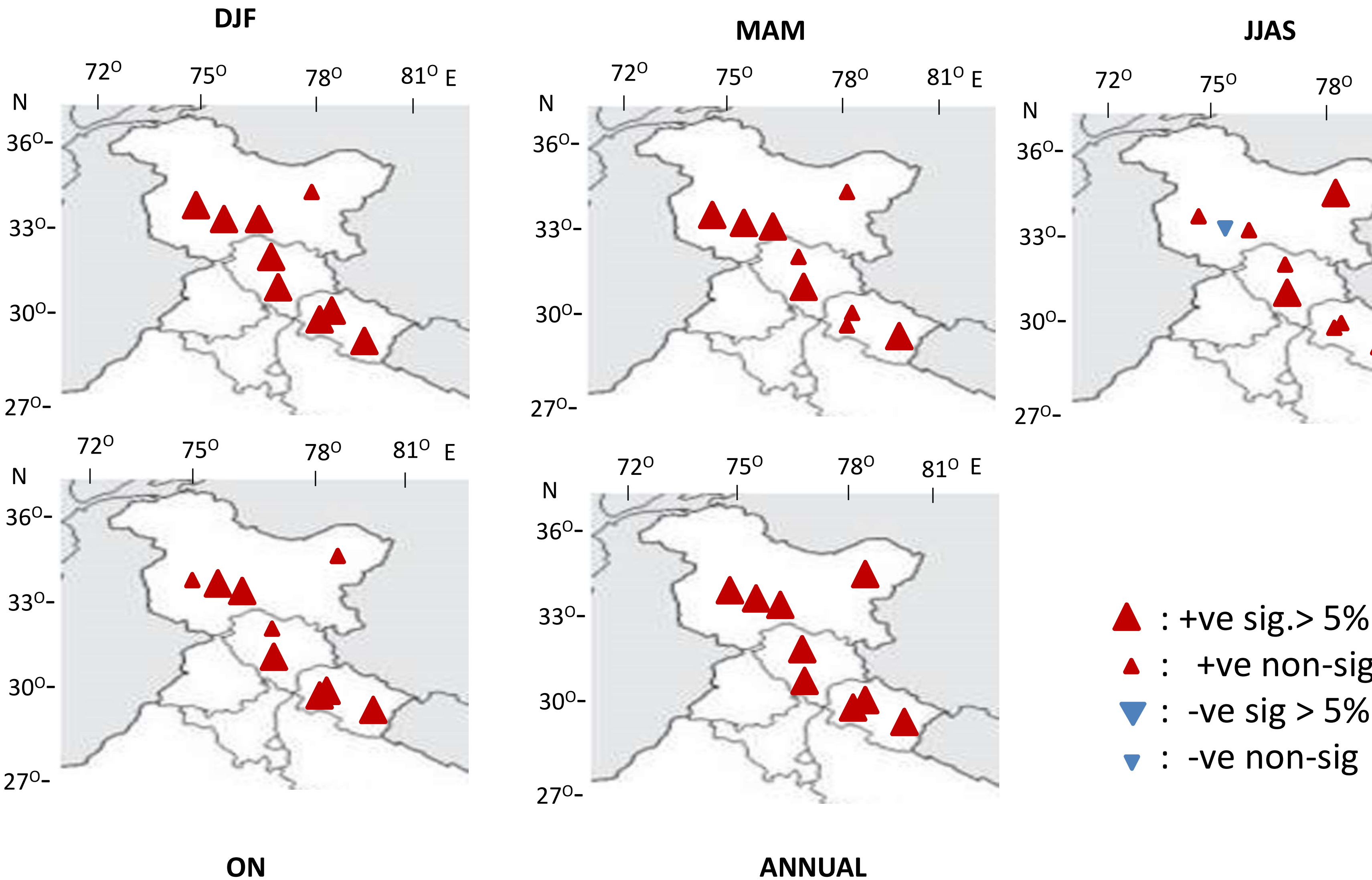
Temperature Analysis

Mean, standard deviation and long-term trends (trend/100 yrs) of max. min and mean temperature over the Western Himalaya

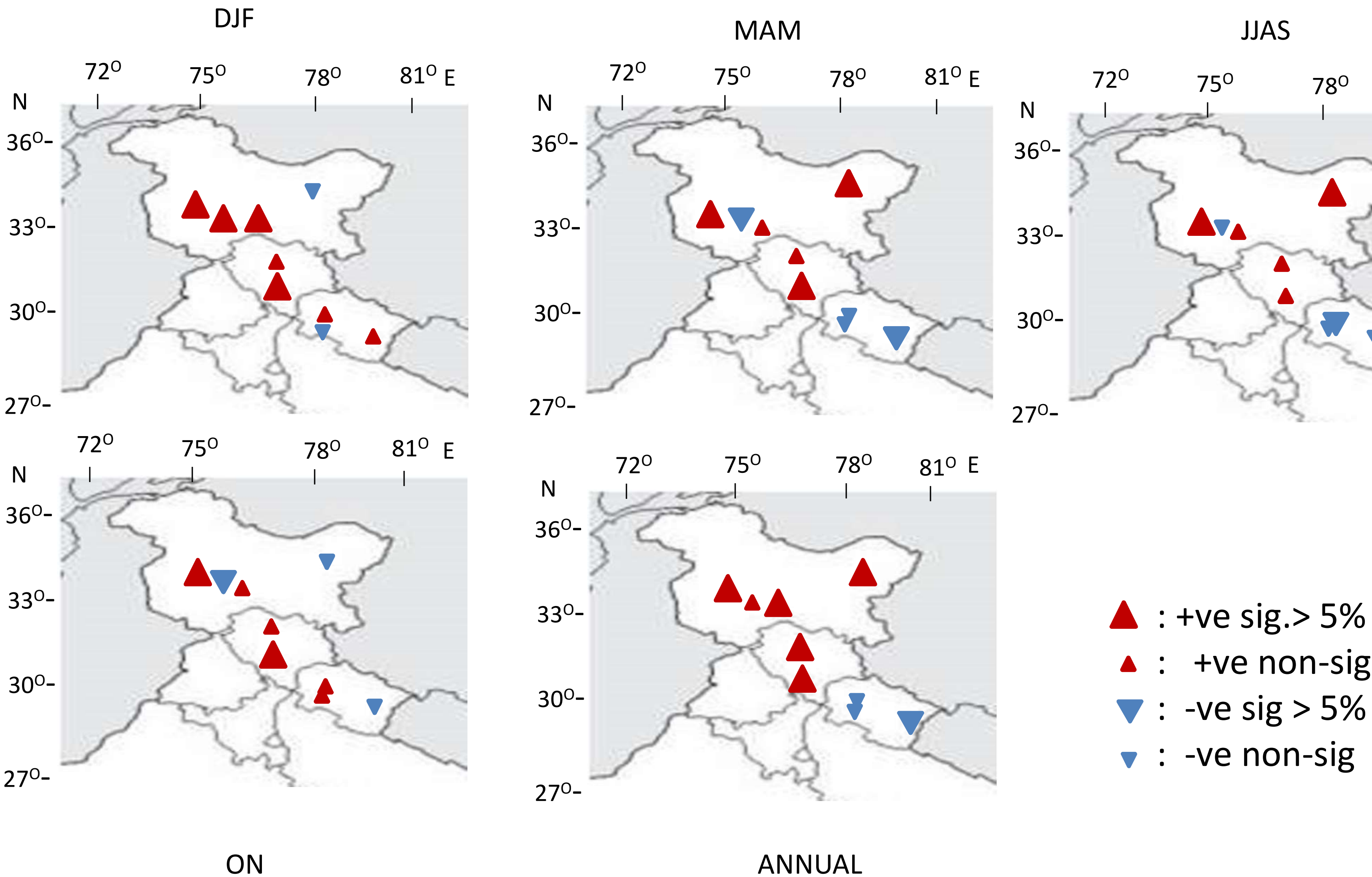
Station	Data Period	Parameter	Winter			Pre-Monsoon			Monsoon			Post-Monsoon			Annual		
			Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Shrinagar	1901-2016	Mean	7.3	-1.6	2.8	19.1	7.3	13.2	29.0	15.7	22.4	18.9	3.0	10.9	19.5	7.2	13.3
		s.d.	2.0	1.1	1.3	1.5	0.7	1.0	0.8	0.8	0.6	1.4	1.2	0.8	0.9	0.6	0.6
		Trend	2.2**	1.1**	1.7**	1.5**	0.7**	1.1**	0.0	0.3*	0.2*	0.6	1.5**	1.0**	1.0**	0.8**	0.9**
Banihal	1962-2016	Mean	11.7	0.7	6.2	21.2	8.1	14.7	28.1	15.5	21.8	21.5	5.3	13.4	21.1	8.3	14.8
		s.d.	1.7	0.9	1.2	1.5	0.9	1.1	0.6	0.7	0.5	1.3	0.9	0.9	0.9	0.6	0.7
		Trend	5.2**	2.4**	3.8**	3.9**	1.1	2.4**	0.7	0.5	0.6	4.0**	1.2	2.6**	3.1**	1.3*	2.2**
Quazigund	1962-2016	Mean	7.8	-2.1	2.8	19.1	6.4	12.7	27.3	14.4	20.9	18.8	3.3	11.1	19.0	6.4	12.7
		s.d.	2.1	1.1	1.4	1.4	0.6	0.9	0.7	0.7	0.6	1.5	0.8	0.8	1.0	0.4	0.6
		Trend	7.6**	2.9**	5.3**	3.4**	-0.8*	1.3*	-0.3	-1.1	-0.7	2.9*	-1.3*	0.8	3.1**	0.0	1.5**
Leh	1901-1990	Mean	1.8	-12.2	-5.2	12.3	-1.1	5.6	23.2	8.6	15.9	11.5	-3.8	3.8	13.2	-1.1	6.0
		s.d.	1.6	1.5	1.1	1.5	1.1	1.2	1.4	1.6	1.4	1.5	1.0	1.1	0.9	1.0	0.9
		Trend	1.4	-0.3	0.6	0.7	2.2**	1.4**	3.4**	3.7**	3.6**	0.6	-0.2	0.2	1.8**	1.8**	1.8**
Shimla	1901-2007	Mean	10.1	3.1	6.6	18.8	10.7	14.8	21.3	15.1	18.2	16.6	9.0	12.8	17.1	10.0	13.5
		s.d.	1.7	1.1	1.3	1.6	1.2	1.4	1.1	0.7	0.8	1.5	0.8	1.1	1.2	0.7	0.9
		Trend	3.8**	1.2*	2.5**	2.9**	0.8*	1.9**	2.7**	0.2	1.4**	3.7**	0.6*	2.2**	3.2**	0.7*	1.9**
Bhunter	1964-2014	Mean	16.9	2.2	9.6	26.8	9.7	18.3	31.3	18.2	24.8	25.4	7.3	16.4	25.6	10.3	18.0
		s.d.	1.5	0.6	0.8	1.5	0.6	1.0	0.7	0.6	0.5	1.1	0.8	0.8	0.6	0.4	0.5
		Trend	5.0**	1.0	3.0**	2.2	1.1	1.6	0.3	1.0	0.6	1.2	1.6	1.4	1.7**	1.1**	1.4**
Dehradun	1901-2015	Mean	20.6	7.1	13.9	31.3	16.7	24.0	31.1	22.4	26.8	26.7	13.2	20.0	27.9	15.6	21.7
		s.d.	1.3	1.0	0.9	1.4	1.2	1.2	0.9	0.8	0.7	1.0	1.0	0.7	0.6	0.8	0.6
		Trend	1.5**	-0.1	0.7*	0.3	-0.5	-0.1	0.1	-0.5	-.01	1.0**	0.0	0.6**	0.6**	-0.3	0.2
Mukteswar	1901-2014	Mean	11.8	2.6	7.2	20.2	9.6	14.9	21.2	13.8`	17.5	17.5	7.8	12.6	18.0	8.9	13.5
		s.d.	1.5	1.0	1.1	1.5	1.3	1.2	0.8	0.8	0.5	1.3	1.0	0.9	0.9	0.8	0.6
		Trend	3.2**	0.1	1.7**	2.0**	-0.6*	0.7	0.9**	-0.6*	0.2	2.2**	-0.3	1.0**	1.9**	-0.4*	0.8**
Massoorie	1901-1990	Mean	11.2	3.4	7.3	20.1	11.1	15.6	21.1	15.3	18.2	16.9	9.2	13.0	17.7	10.3	14.0
		s.d.	1.4	0.8	1.0	1.3	1.1	1.1	0.5	0.5	0.4	0.9	0.7	0.7	0.6	0.5	0.5
		Trend	2.6**	0.2	1.4**	0.8	-0.1	0.4	0.2	-0.4*	-0.1	1.9**	0.2	1.1**	1.2**	-0.1	0.5**

* $p < 0.05$; ** $p < 0.01$

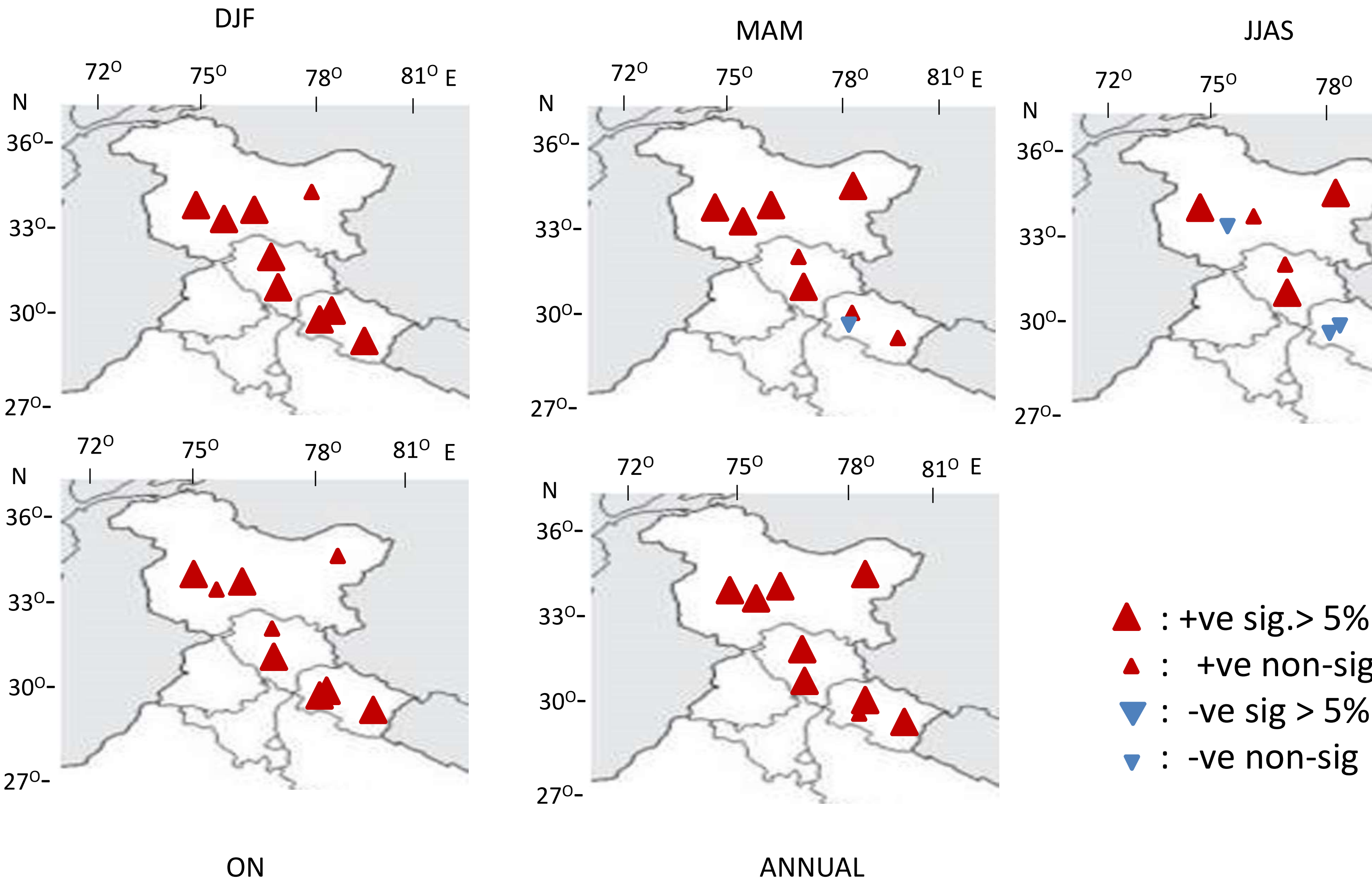
Long-term trends(trend/100 yrs.) in maximum temperature

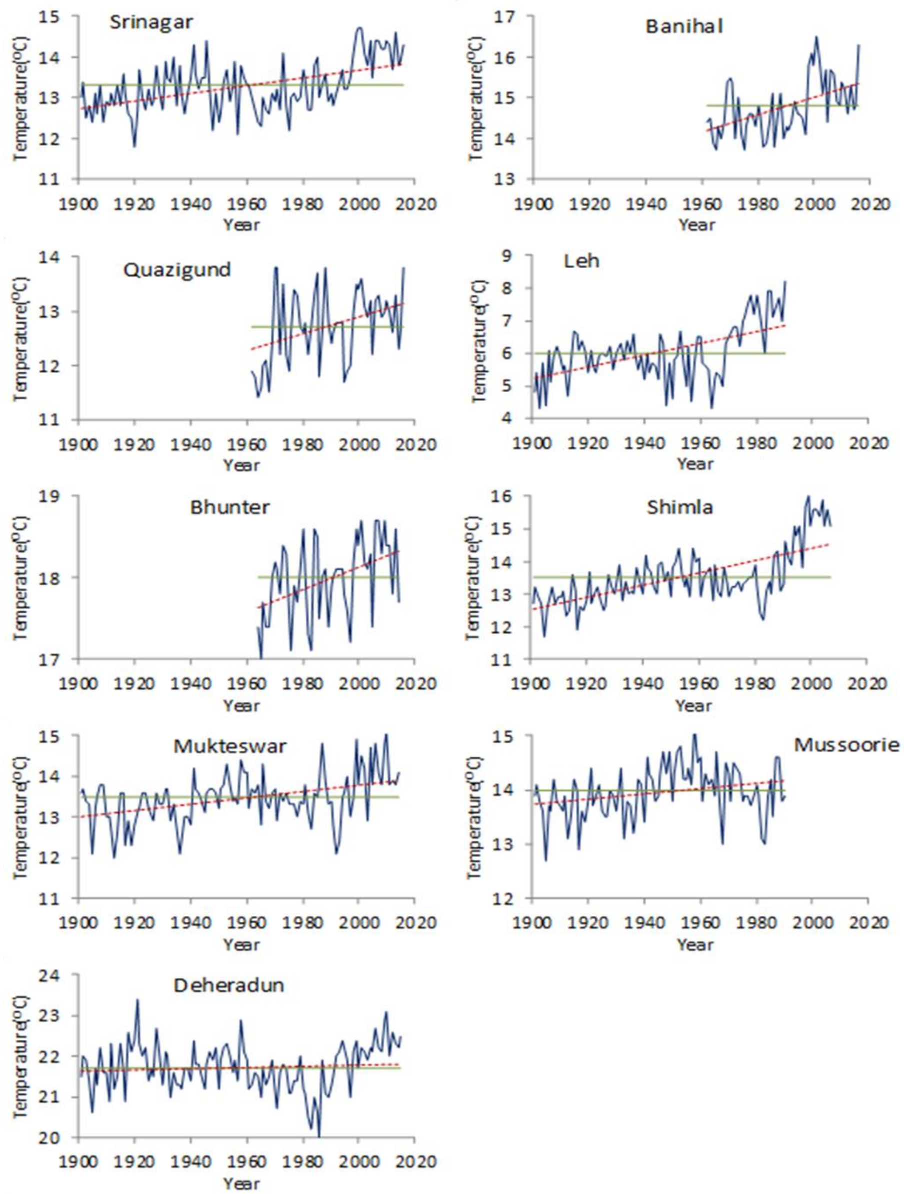


Long-term trends(trend/100 yrs.) in minimum temperature

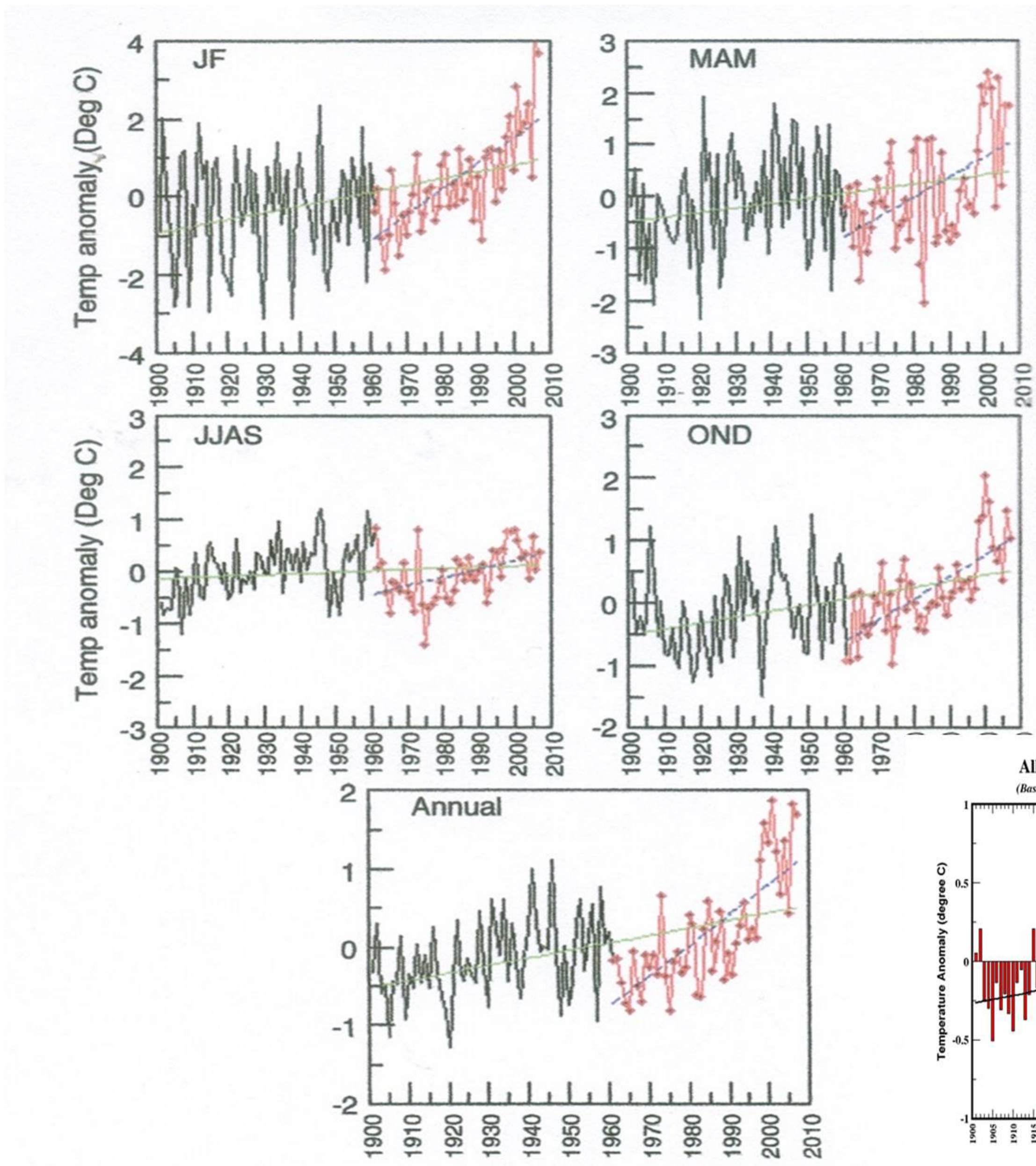


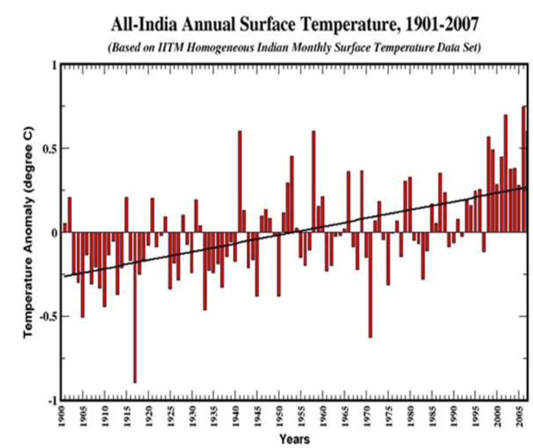
Long-term trends(trend/100 yrs.) in Mean Temperature





Annual mean surface temperature variations of western Himalayan stations with linear trend in red dotted line. Mean line is in green colour

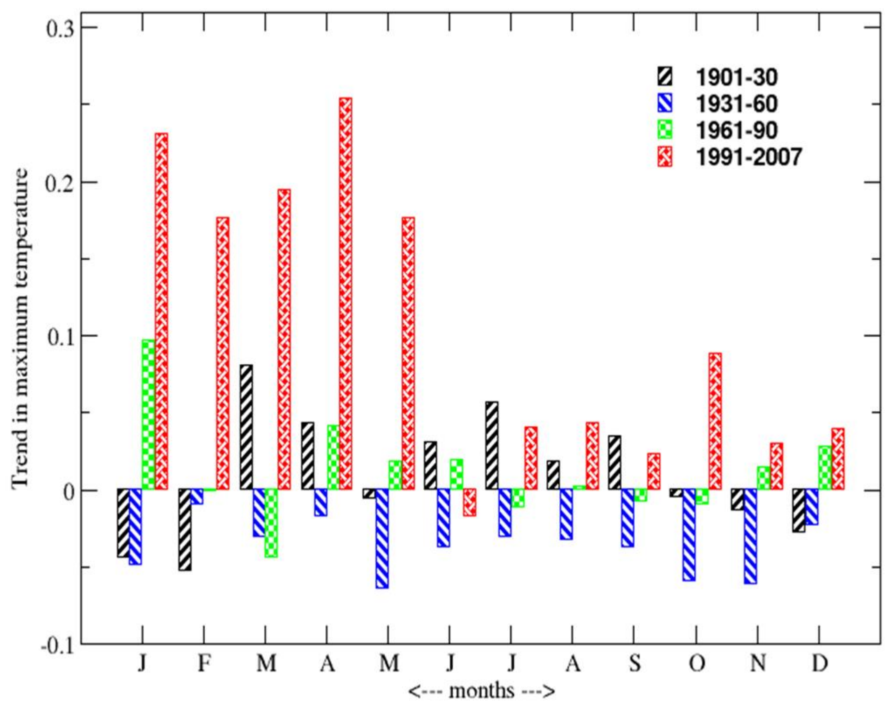




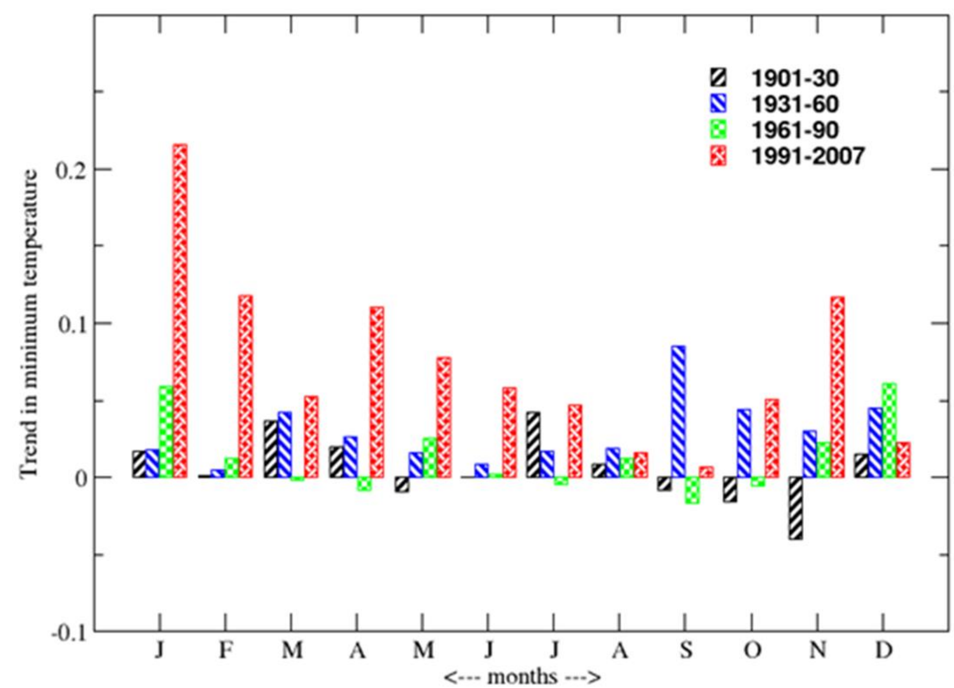
Mean surface temperature series over western Himalaya for different seasons with linear trends for the total period 1901-2007 (solid green line) and recent five decades 1961-2007 (dashed blue line) based on IITM data (freely available at www.tropmet.res.in).

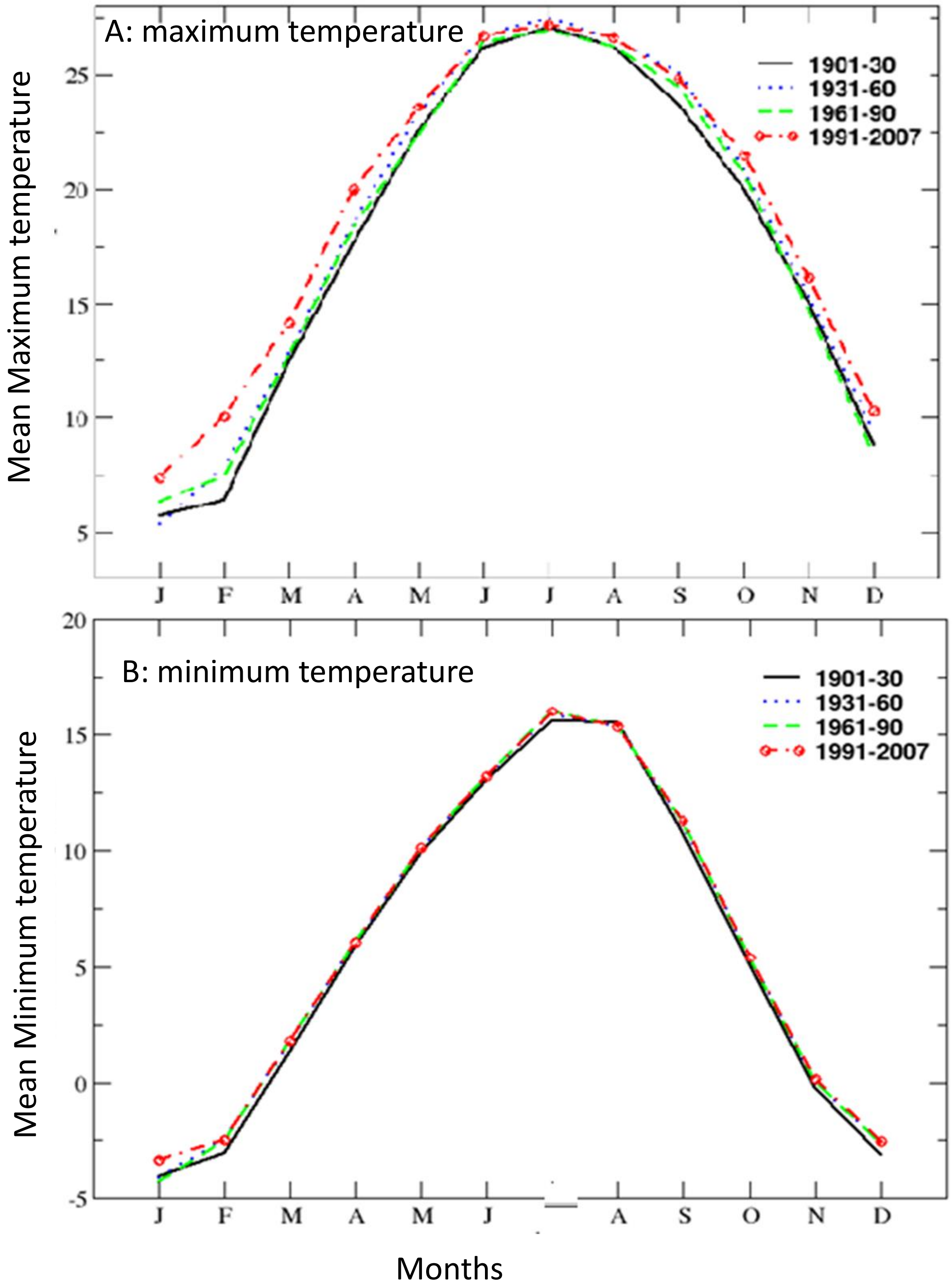
Monthly trend values of mean maximum and minimum temperature over western Himalaya for successive 30 years period since 1901.

Maximum temperature

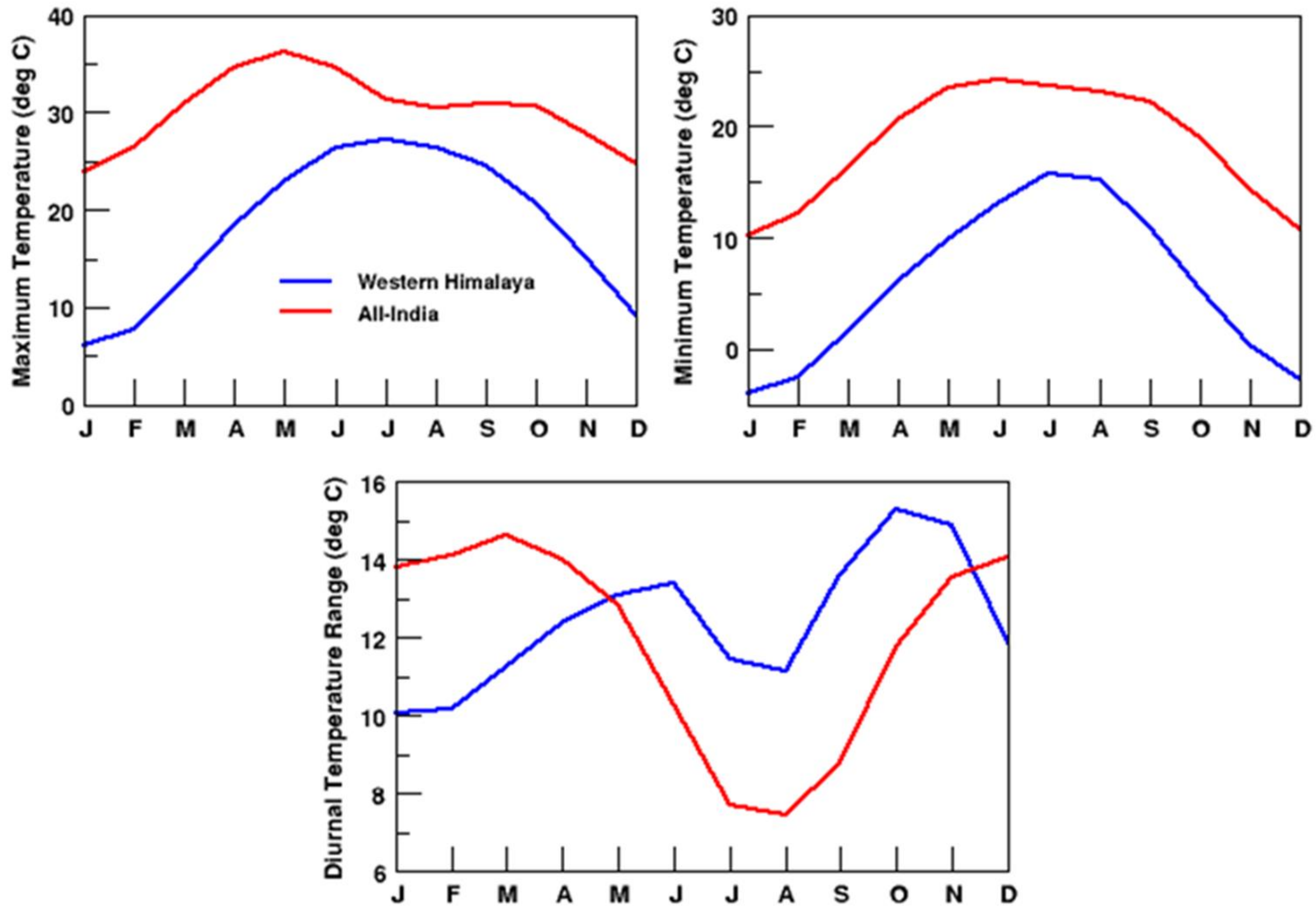


Minimum temperature

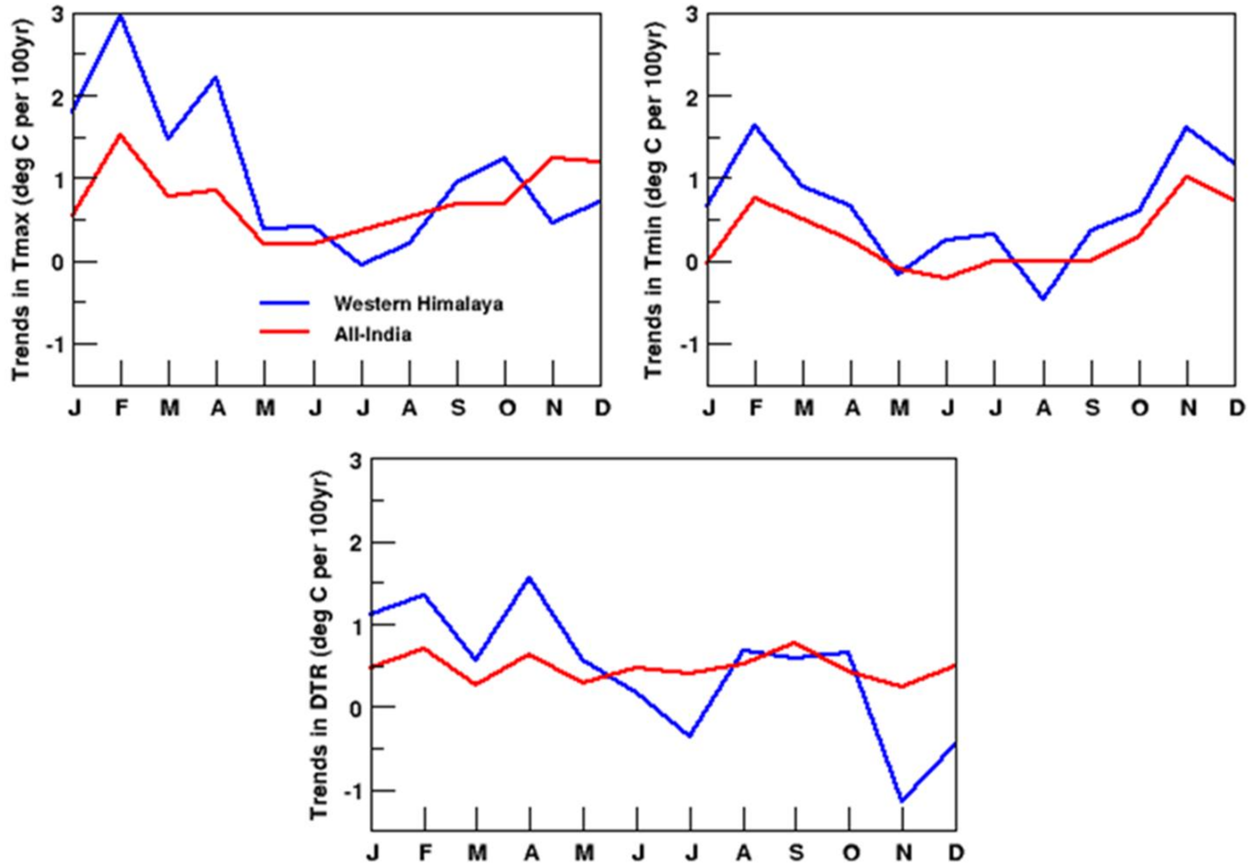




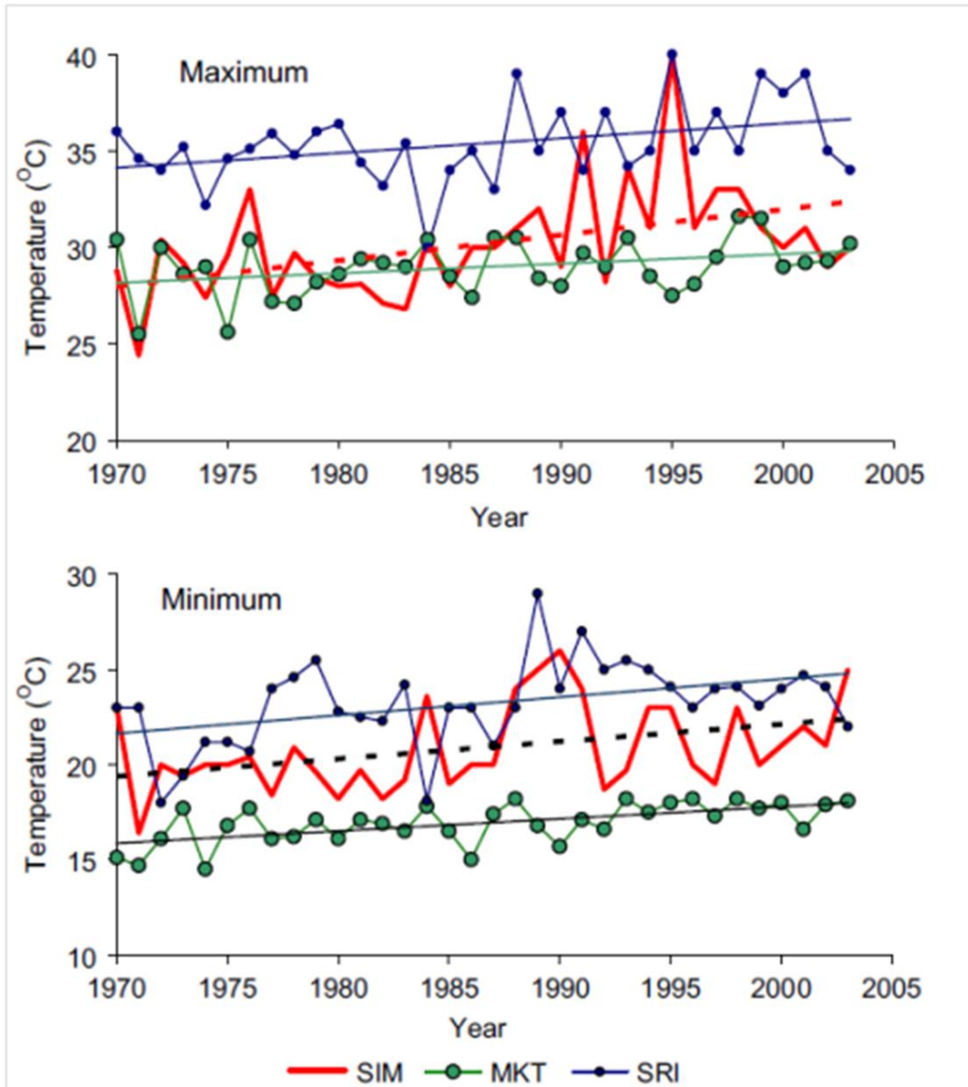
Successive increase in monthly mean maximum (A) and minimum (B) temperature for 30-year periods since 1901



Annual cycle in maximum, minimum temperature and diurnal temperature range over western Himalaya (Blue) in comparison with All-India data (Red)



Trends in maximum, minimum temperature and diurnal temperature range over western Himalaya (Blue) in comparison with All-India data (Red)



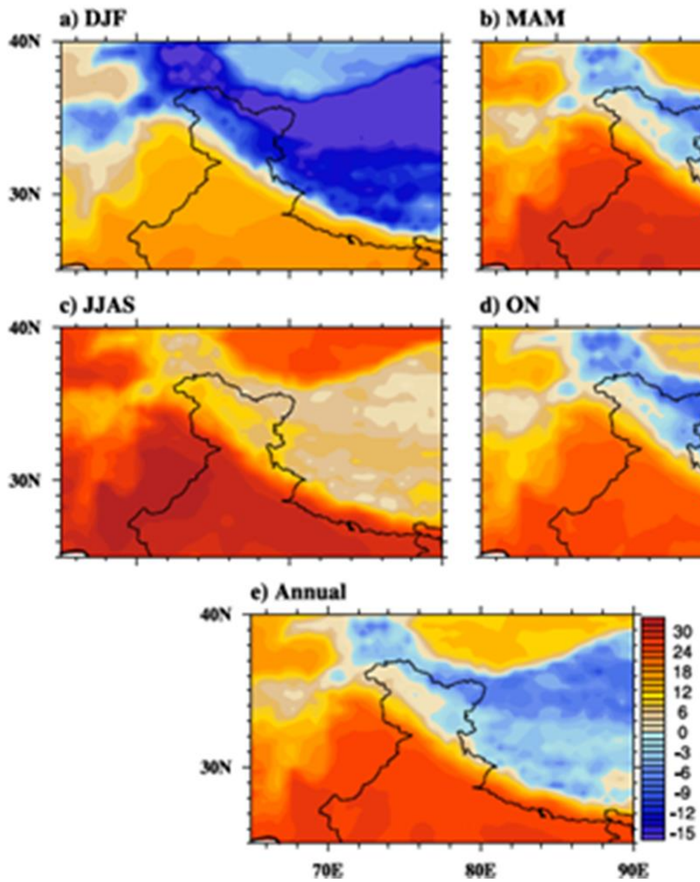
Annual highest values of daily Maximum and Minimum temperature at three stations in western Himalaya; Srinagar (SRN), Shimla (SIM) and Mukteshwar (MKT)

Extreme temperature events and the corresponding years at three stations of Garhwal-Kumaon Himalaya

Station	Extreme events	Maximum Temperature (^{O}C)					Minimum Temperature (^{O}C)					Mean Temperature (^{O}C)				
		DJF	MAM	JJAS	ON	Annual	DJF	MAM	JJAS	ON	Annual	DJF	MAM	JJAS	ON	Annual
MAS	Highest (year)	14.3 (1988)	**23.1 (1921)**	22.7 (1903)	18.7 (1943)	19.1 (1958)	5.3 (1988)	**13.9 (1921)**	16.3 (1903)	10.7 (1915)	11.5 (1958)	9.7 (1988)	**18.5 (1921)**	19.5 (1903)	14.4 (1976)	15.2 (1958)
	Lowest (year)	**7.2 (1905)**	16.6 (1917)	20.1 (1971)	14.9 (1911)	**16.1 (1905)**	**1.2 (1905)**	8.6 (1983)	13.6 (1968)	7.0 (1968)	8.6 (1968)	**4.2 (1905)**	12.6 (1917)	17.2 (1968)	11.5 (1911)	12.7 (1905)
DDN	Highest (year)	23.5 (1990)	**33.7 (1921)**	34.1 (1958)	28.9 (1979)	29.1 (1958)	9.9 (1922)	**21.2 (1921)**	23.9 (1921)	15.3 (1951)	18.1 (1921)	15.4 (1921)	**27.4 (1921)**	28.6 (1918)	22.0 (1920)	23.4 (1921)
	Lowest (year)	**16.8 (1905)**	25.2 (1907)	28.0 (1911)	23.3 (1917)	26.1 (1911)	4.6 (1971)	13.7 (1983)	19.6 (1986)	10.8 (1986)	12.9 (1986)	**11.4 (1905)**	20.2 (1907)	24.4 (1985)	18.2 (1985)	20.0 (1986)
MKT	Highest (year)	13.7 (1967)	**23.1 (1921)**	23.2 (1987)	20.6 (1986)	20.2 (1987)	4.7 (1948)	12.1 (1941)	15.2 (1931)	10.4 (1907)	10.3 (1932)	8.7 (1967)	**17.1 (1921)**	18.6 (1987)	14.9 (1987)	14.8 (1987)
	Lowest (year)	**7.0 (1905)**	17.1 (1905)	19.4 (1936)	14.9 (1926)	**16.2 (1905)**	**0.0 (1905)**	6.4 (1990)	12.2 (1913)	5.7 (1921)	7.2 (1990)	**3.5 (1905)**	12.2 (1917)	16.0 (1936)	10.4 (1921)	12.0 (1913)

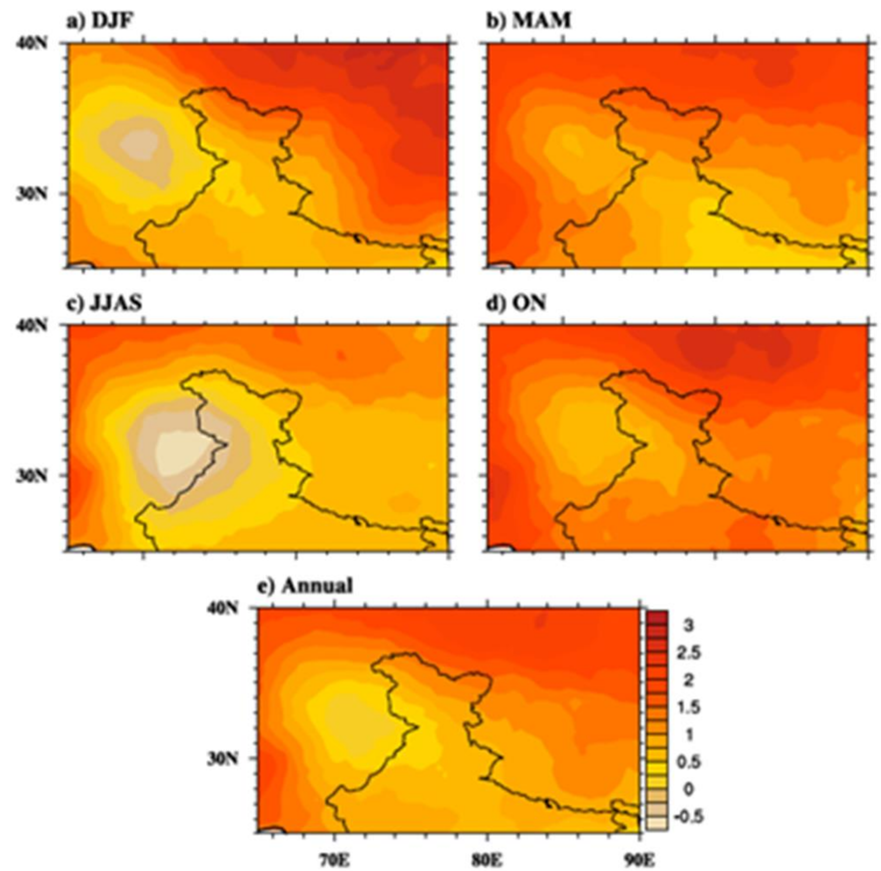
MAS: Massoorie; DDN: Dehradun; MKT: Mukteswar

Surface mean temperature patterns



Surface mean temperature patterns for different seasons over the Himalaya based on CRU data for the period 1951-2017 CE.

The Observed trend in temperature



The Observed trend in temperature over the Himalaya for different seasons based on CRU data for the period 1951-2007 CE.

Linear trend in annual and seasonal temperature (°C) for India and 7 homogeneous regions within India: western Himalaya (WH), northwest (NW), north-central (NC), northeast (NE), west coast (WC), east coast (EC) and interior peninsula (IP). DJF: previous year Dec–Feb; MAM: pre-monsoon Mar–May; JJAS: monsoon Jun–Sep; ON: post-monsoon Oct–Nov. *$p < 0.05$; **$p < 0.01$

Region	Temperature	1901–2007 (°C 100 yr^{-1})					1971–2007 (°C 10 yr^{-1})				
		DJF	MAM	JJAS	ON	Annual	DJF	MAM	JJAS	ON	Annual
India	Maximum	1.1**	0.61**	0.43**	0.96**	0.72**	0.27**	0.10	0.10	0.21**	0.17**
	Minimum	0.46*	0.23	−0.06	0.64**	0.27*	0.30**	0.18*	0.18**	0.18	0.20**
	Mean	0.8**	0.42*	0.20*	0.82**	0.51**	0.30**	0.14	0.14**	0.20	0.20**
WH	Maximum	1.8**	1.3*	0.38	0.85	1.0*	0.82*	0.68*	0.22*	0.49*	0.53*
	Minimum	1.16**	0.45	0.10	1.10**	0.61*	0.47**	0.30*	0.40**	0.26	0.37**
	Mean	1.5**	0.91*	0.24	1.00*	0.86**	0.68**	0.49*	0.35*	0.39*	0.46**
NW	Maximum	0.88**	0.50	0.25	0.67	0.53**	0.28*	0.18	0.19	0.23	0.22*
	Minimum	−0.18	0.00	−0.26*	0.15	−0.11	0.40	0.25**	0.11*	0.18	0.24**
	Mean	0.34	0.28	−0.02	0.40	0.21	0.34**	0.22	0.15	0.21	0.22**
NC	Maximum	0.82**	0.60*	0.45*	1.1**	0.67**	0.15	0.03	0.08	0.17	0.10
	Minimum	0.60**	0.16	−0.23	1.06**	0.29	0.36**	0.19	0.20**	0.19	0.22*
	Mean	0.71**	0.36	0.09	1.10**	0.50**	0.25*	0.11	0.13*	0.20	0.17**
NE	Maximum	1.2**	0.66*	0.72**	1.4**	0.95**	0.17	−0.02	0.09	0.17*	0.09*
	Minimum	0.64	0.15	−0.23	0.60	0.22	0.34**	0.23*	0.22**	0.19	0.24**
	Mean	0.95**	0.39	0.25*	1.02**	0.60**	0.27**	0.11	0.17**	0.19	0.18**
WC	Maximum	1.6**	0.99**	0.90**	1.3**	1.1**	0.29**	0.16*	0.13	0.18*	0.19**
	Minimum	0.21	0.30*	0.28**	0.42*	0.27*	0.25*	0.15**	0.16**	0.20	0.18*
	Mean	0.91**	0.63**	0.59**	0.84**	0.74**	0.27**	0.16*	0.15**	0.19*	0.19**
EC	Maximum	1.0**	0.46*	0.36*	0.81**	0.63**	0.25**	0.10	0.06	0.09	0.11**
	Minimum	0.54*	0.40**	0.11	0.43*	0.35*	0.16	0.15**	0.14*	0.13	0.13*
	Mean	0.79**	0.41**	0.24*	0.60**	0.49**	0.20*	0.13*	0.10	0.11	0.12*
IP	Maximum	0.93**	0.36	0.28	0.68*	0.54**	0.27**	0.03	0.05	0.18	0.12*
	Minimum	0.53*	0.39*	0.24*	0.60*	0.44**	0.09	0.05	0.11*	0.11	0.09
	Mean	0.73**	0.34*	0.26*	0.63**	0.48**	0.18*	0.04	0.09	0.13	0.10*

Kothawale et al. 2010

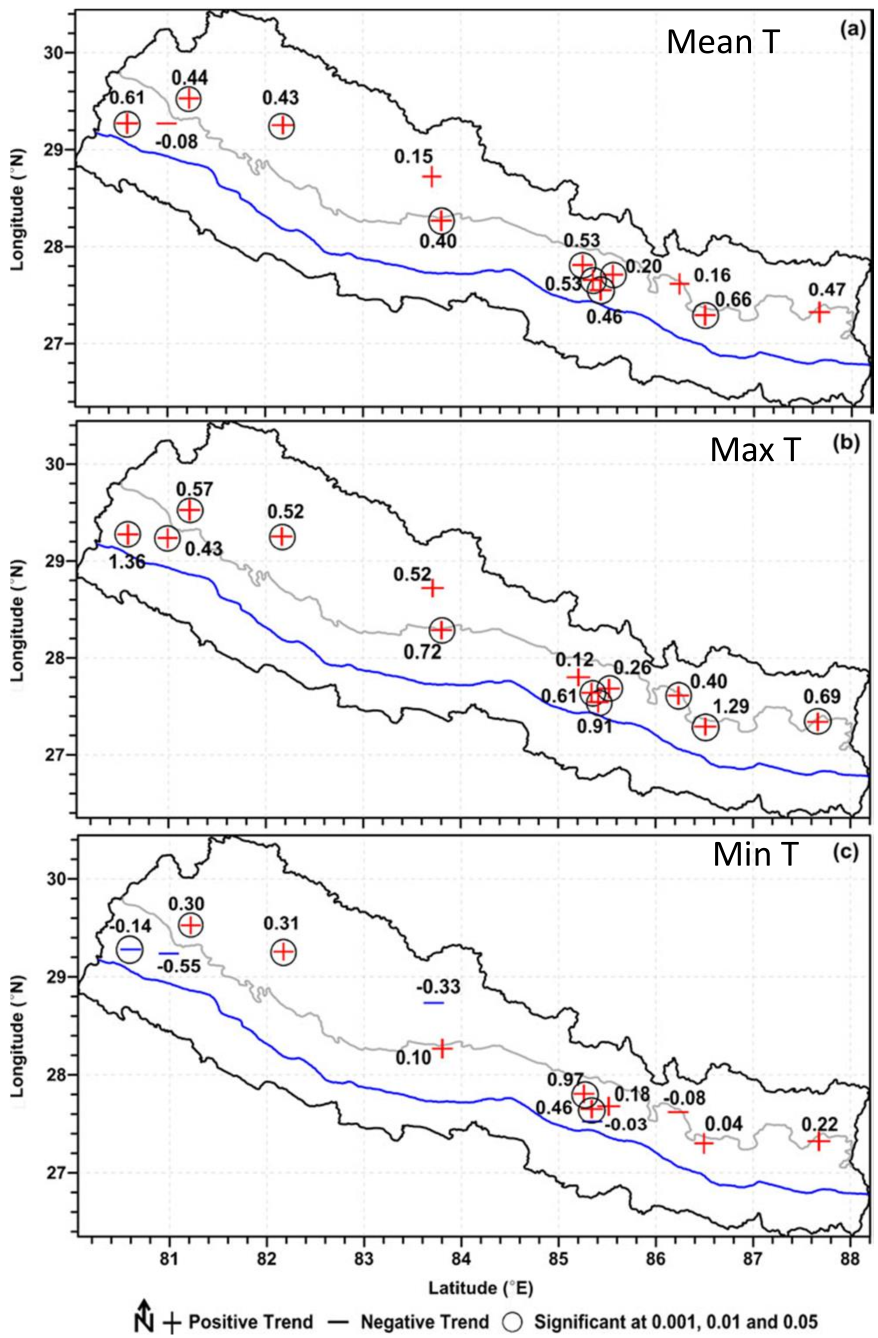
Linear trends in annual and seasonal mean temperature (^{O}C / 100 yr.) for global, India and western Himalaya (W.H.) for the period 1901-2007

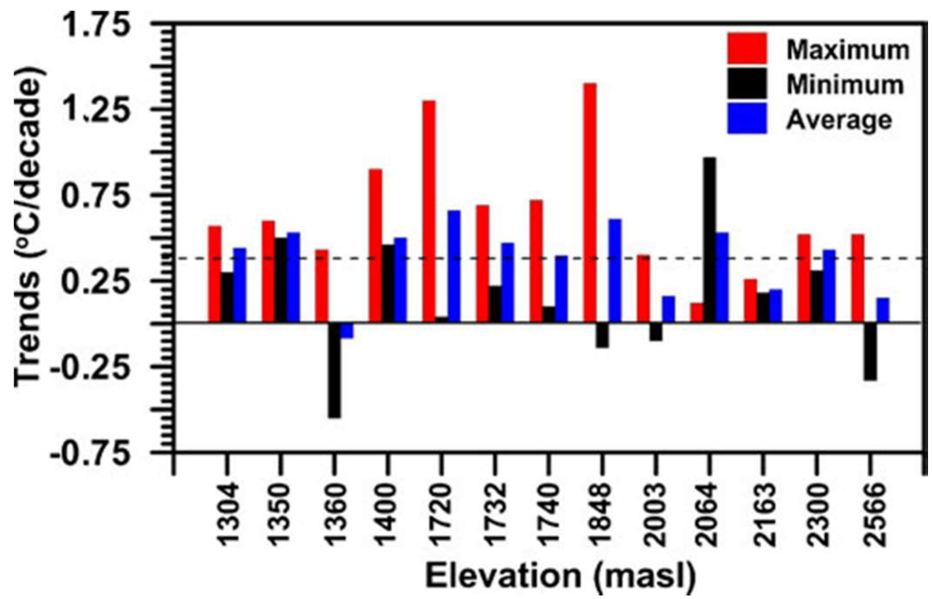
	DJF	**MAM**	**JJAS**	**ON**	**ANNUAL**
Global	0.89	0.94	0.72	0.76	0.82
India	0.80	0.42	0.20	0.82	0.51
W.H.	1.5	0.91	0.24	1.0	0.86

Kothawale et al. 2010

Temperature trends over Nepal

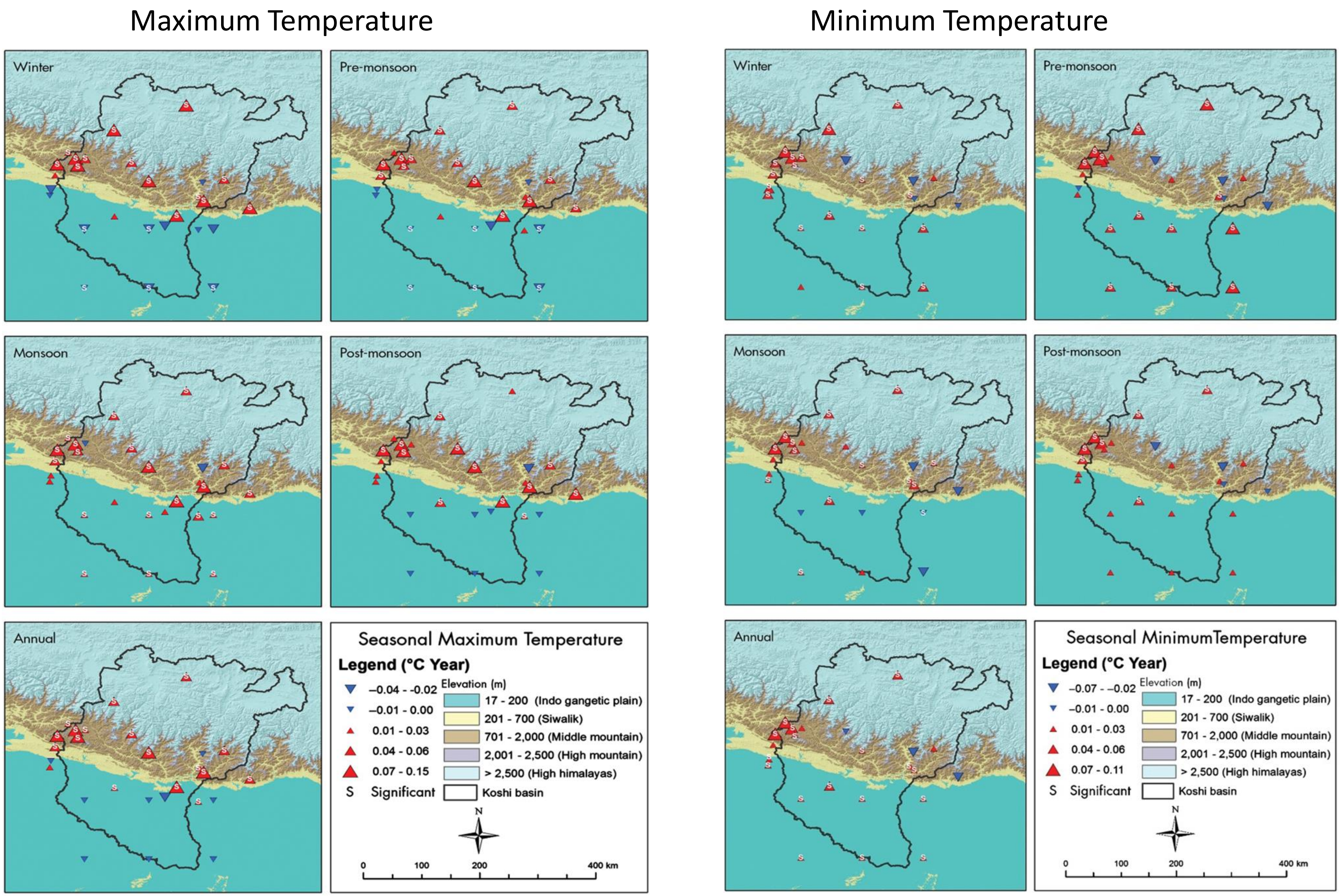
(Kattel *and Yao, 2013)*





Monthly mean maximum and minimum temperature data from **13 stations** covering the period from 1980 to 2009 .

Elevation range from 1304 m in the south to 2566 m in North.



Trends in maximum and minimum seasonal temperature for 1975–2010 over the Koshi river basin including parts of Tibet (China), Nepal and India (Shrestha *et al.* 2017).

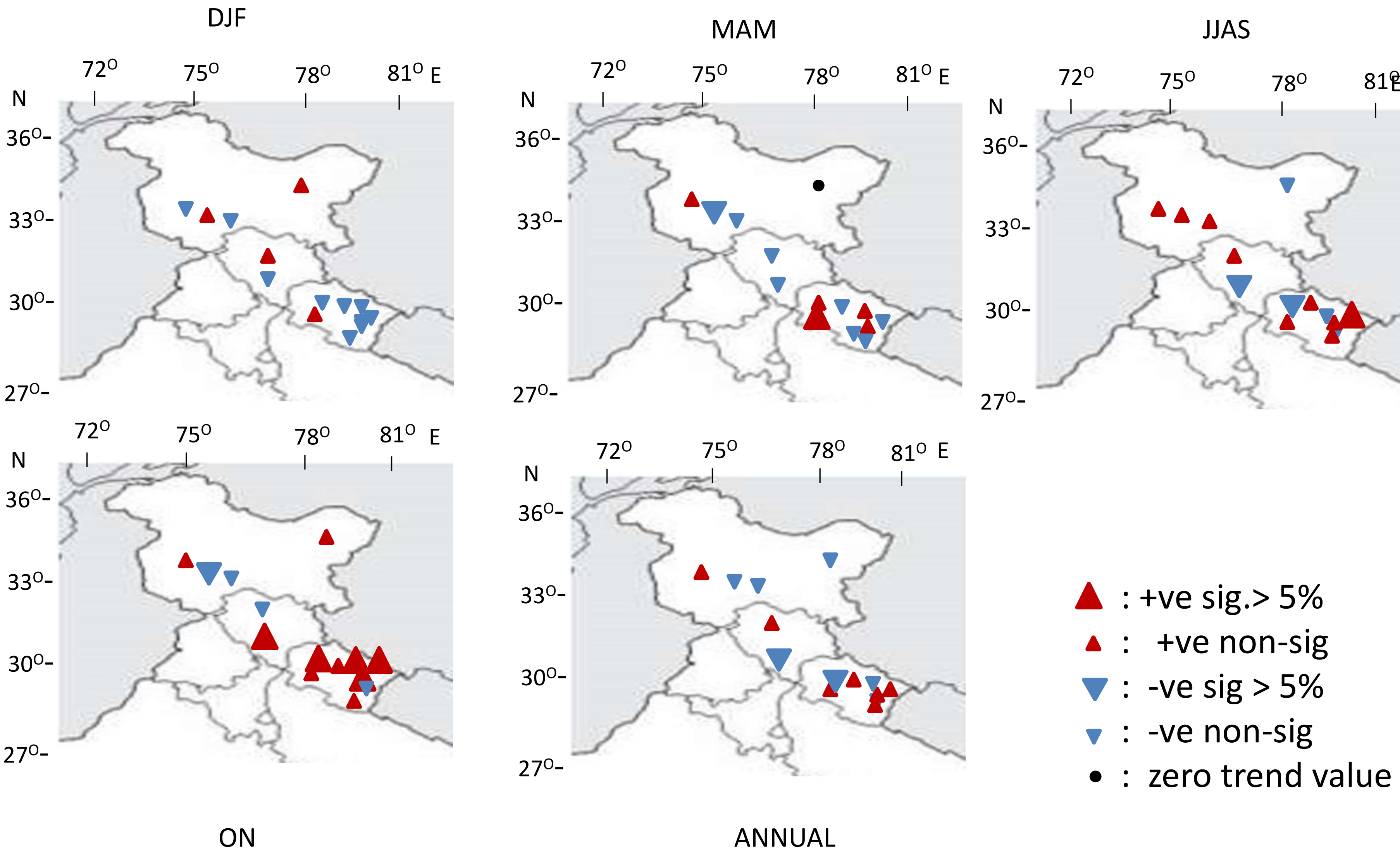
Rainfall Analysis

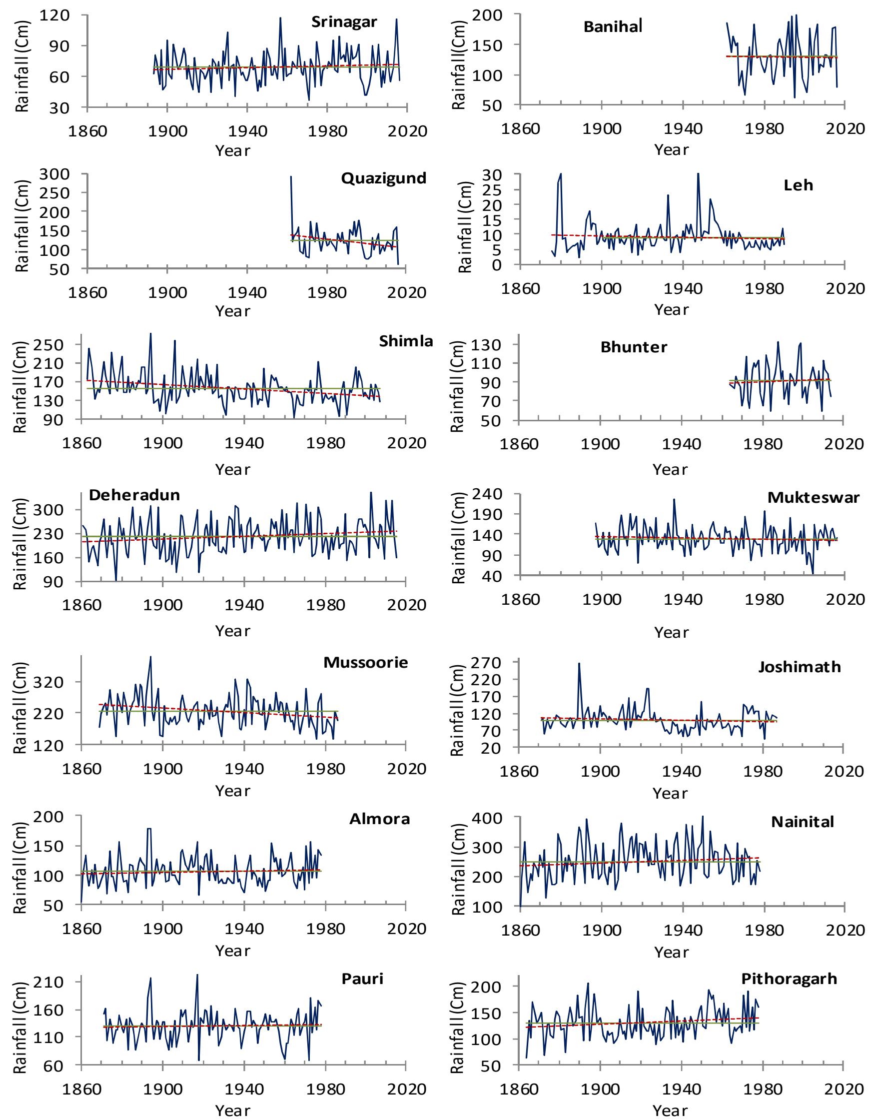
Mean, standard deviation and long-term trends of rainfall over the Western Himalaya

Station	Data Period	Parameter	Winter	Pre-Monsoon	Monsoon	Post-Monsoon	Annual
Shrinagar	1893-2016	Mean	17.9	25.9	19.7	5.0	68.4
		s.d.	7.5	9.3	7.3	4.3	15.4
		Trend	-0.6	2.9	1.1	1.5	4.4
Banihal	1962-2016	Mean	57.2	43.6	31.6	8.8	129.1
		s.d.	90.8	18.3	16.7	6.3	97.3
		Trend	-115.8	-2.1	8.7	-5.0	-125.0
Quazigund	1962-2016	Mean	38.4	42.1	31.9	11.1	123.1
		s.d.	13.9	14.5	15.1	21.6	36.0
		Trend	8.0	-32.9**	10.3	-36.6*	-59.4
Leh	1876-1990	Mean	2.3	2.2	3.8	0.7	9.0
		s.d.	1.4	2.2	2.5	1.2	4.2
		Trend	0.1	0.0	-1.4	0.7	-0.8
Shimla	1863-2007	Mean	16.6	19.1	114.7	4.8	155.3
		s.d.	9.5	10.4	27.7	5.6	30.5
		Trend	-2.7	-1.0	-21.9**	1.6*	-24.0**
Bhunter	1964-2014	Mean	23.1	25.9	37.6	4.4	91.1
		s.d.	9.4	10.1	12.5	4.6	18.0
		Trend	3.4	-3.2	12.5	-1.9	8.9
Dehradun	1861-2015	Mean	14.0	10.9	189.9	4.9	219.6
		s.d.	8.4	8.2	47.8	6.2	48.7
		Trend	0.8	4.2*	12.7	2.3	19.7
Mukteswar	1897-2015	Mean	13.4	14.7	96.2	5.7	129.9
		s.d.	7.1	7.2	27.2	8.5	29.9
		Trend	-1.1	2.1	-9.9	-1.2	-10.6
Massoorie	1869-1986	Mean	15.2	15.0	190.2	5.3	225.8
		s.d.	8.1	8.1	44.5	7.3	46.6
		Trend	-4.1	0.6	-35.2**	4.2*	-34.4*
Almora	1856-1980	Mean	11.3	12.1	78.3	4.4	106.1
		s.d.	6.0	6.3	20.6	6.5	23.4
		Trend	-1.1	-1.9	6.3	2.9*	6.2
Joshimath	1871-1980	Mean	18.2	19.6	58.2	4.4	100.4
		s.d.	10.9	10.7	23.1	5.0	31.1
		Trend	-3.8	1.0	-9.9	1.8*	-11.0
Nainital	1849-1980	Mean	17.1	16.5	210.2	8.0	251.8
		s.d.	10.9	10..5	56.4	13.3	61.1
		Trend	-3.0	-0.4	12.7	5.1	14.3
Pauri	1871-1980	Mean	15.0	13.6	97.2	4.3	130.0
		s.d.	7.9	7.6	23.5	6.5	26.9
		Trend	-1.5	-1.9	5.2	2.2	3.8
Pithoragarh	1864-1980	Mean	12.4	15.0	97.8	4.9	130.2
		s.d.	7.0	7.8	25.0	6.9	28.2
		Trend	-1.0	-0.6	13.0*	3.4*	14.7

Trend values indicate Trend/100 years; * $p < 0.05$; ** $p < 0.01$

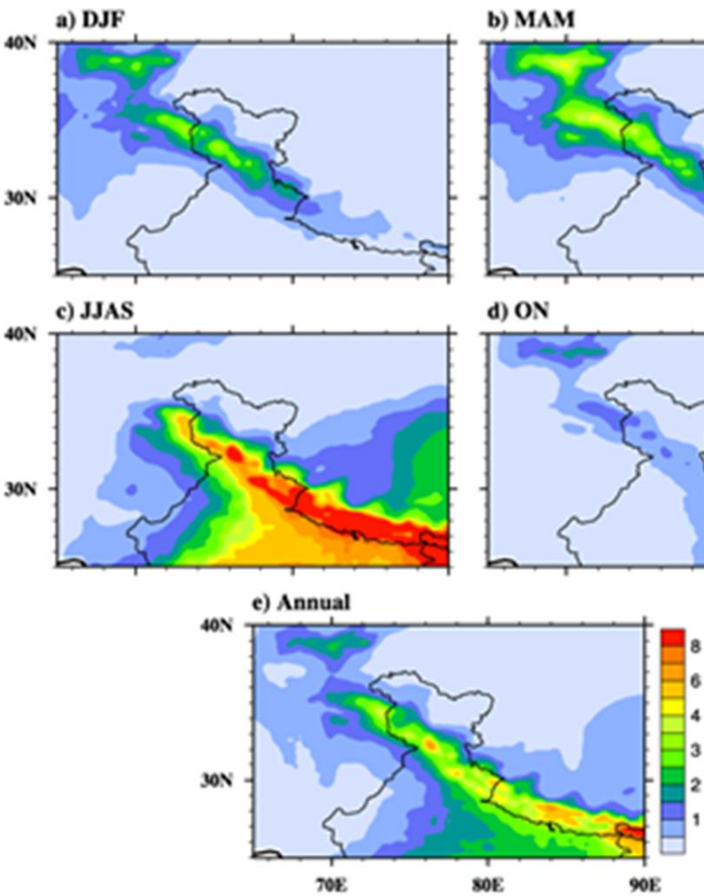
Long-term trends(trend/100 yrs.) in Rainfall





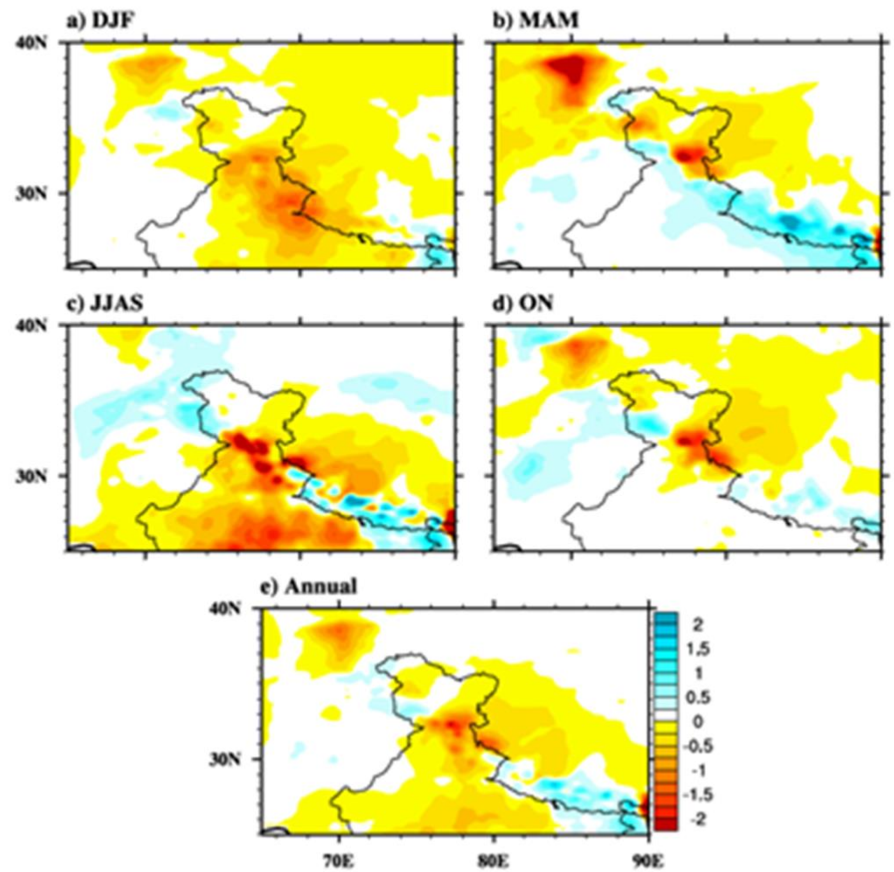
Annual rainfall variations of 14 western Himalayan stations with linear trend in red dotted lines. Mean line is in green colour.

Mean Precipitation patterns



Mean Precipitation patterns for different seasons over the Himalaya based on APHRODITE data for the period 1951-2007 CE.

Observed trend in precipitation

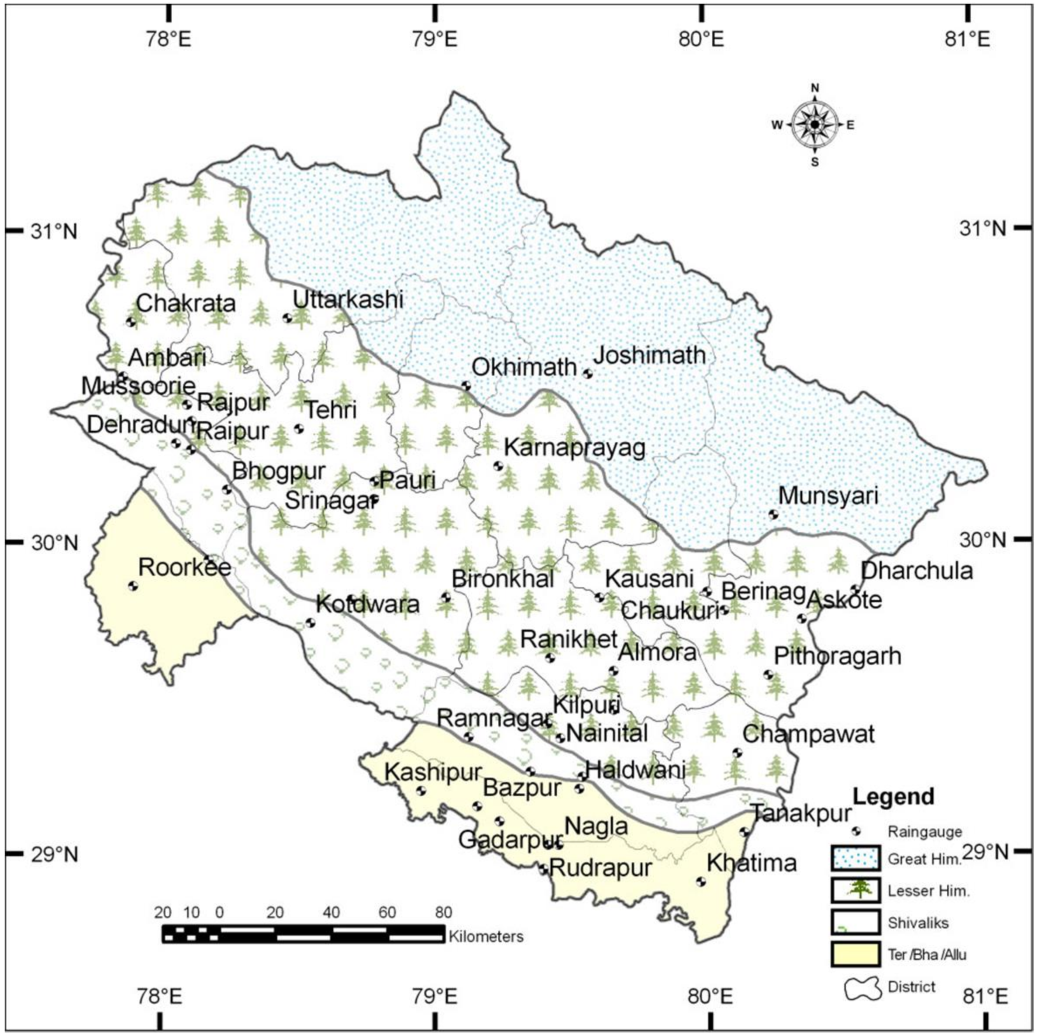


The Observed trend in precipitation over the Himalaya for different seasons based on APHRODITE data for the period 1951-2007 CE.

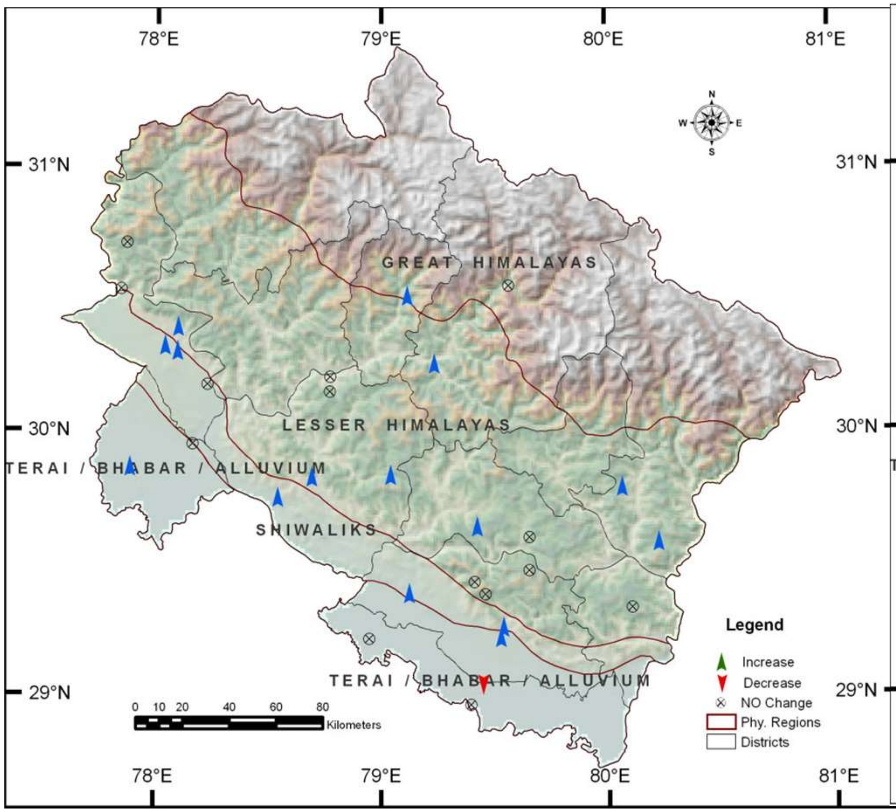
Highest and Lowest Rainfall values in cm. and the corresponding years

Station	Parameter	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Mussoorie	High	42.2 (1895)	36.1 (1878)	335.6 (1894)	46.4 (**1956**)	399.6 (1894)
	Low	0.0 (1960)	2.5 (1938)	73.9 (1877)	0.0 (many years)	136.3 (1976)
Dehradun	High	65.5 (1977)	70.0 (1983)	293.0 (1966)	33.0 (**1956**)	319.1 (1966)
	Low	0.0 (1876)	1.1 (1922)	47.0 (1877)	0.0 (many years)	93.9 (1877)
Pauri	High	37.6 (1954)	45.5 (1877)	168.1 (1894)	39.5 (**1956**)	228.4 (1917)
	Low	0.9 (1960)	1.5 (1892)	41.9 (1977)	0.0 (many years)	67.7 (1918)
Almora	High	32.2 (1954)	27.0 (1907)	130.8 (1879)	35.6 (**1956**)	178.0 (1894)
	Low	0.7 (1967)	0.5 (1922)	25.7 (1877)	0.0 (many years)	55.6 (1860)
Nainital	High	47.8 (1893)	44.0 (1950)	340.9 (1950)	81.8 (**1956**)	410.6 (1950)
	Low	0.0 (many years)	0.0 (1934)	52.1 (1860)	0.0 (many years)	81.5 (1860)
Joshimath	High	54.2 (1891)	52.2 (1950)	200.3 (1890)	27.8 (**1956**)	268.1 (1890)
	Low	1.3 (1946)	2.2 (1934)	16.5 (1965)	0.0 (many years)	51.6 (1943)
Pithoragarh	High	29.7(1878)	40.4 (1946)	166.9 (1897)	39.9 (**1956**)	206.7 (1894)
	Low	0.9 (1922)	1.1 (1922)	43.7 (1864)	0.0 (many years)	62.7 (1864)
Mukteswar	High	36.6 (1905)	36.6 (1917)	183.9 (1936)	46.1 (**1956**)	225.4 (1936)
	Low	2.0 (1932)	1.9 (1921)	46.7 (1979)	0.0 (many years)	69.4 (1918)

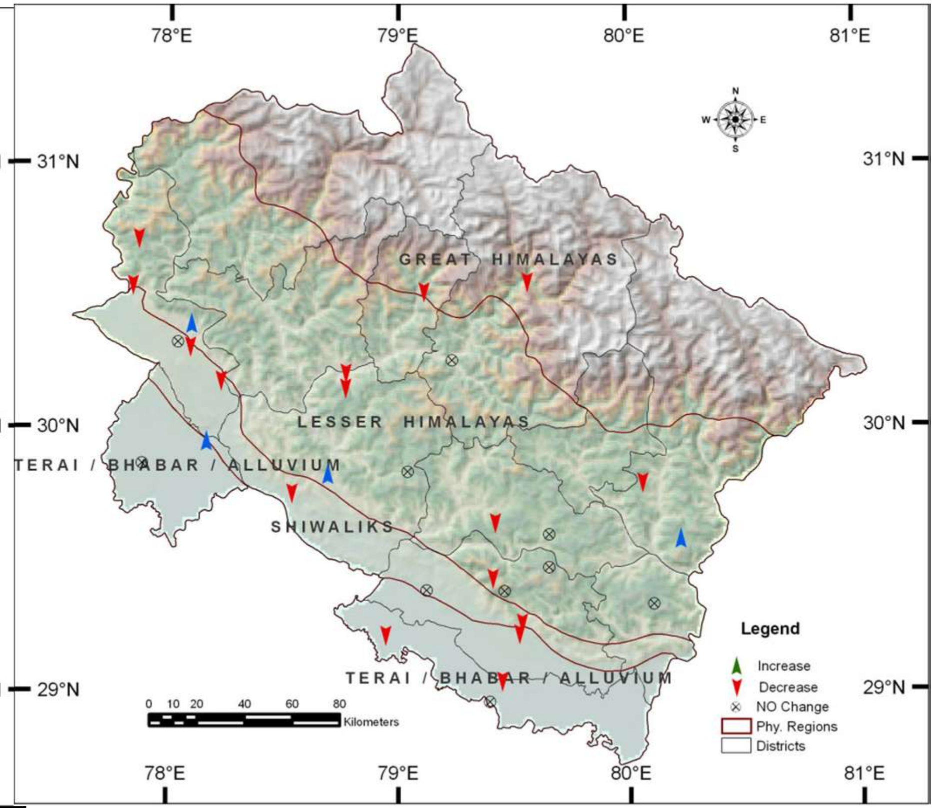
Analysis of historical changes in rainfall in the Uttarakhand Himalayas
(Basistha et al. 2008)



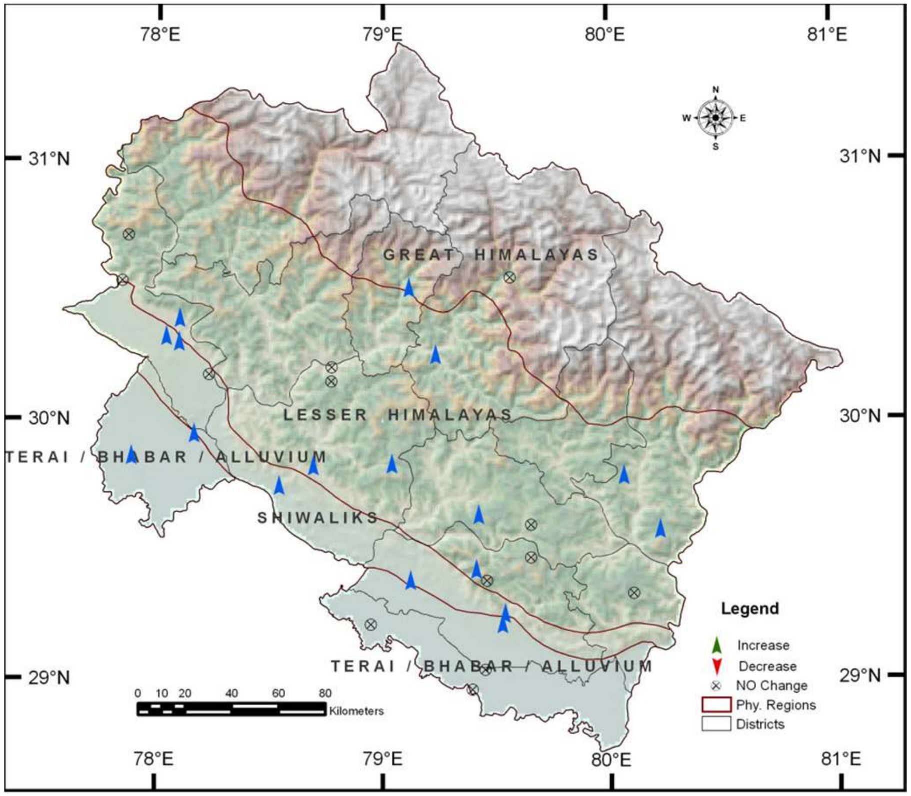
Location of rain gauges in Uttarakhand (31 stations)



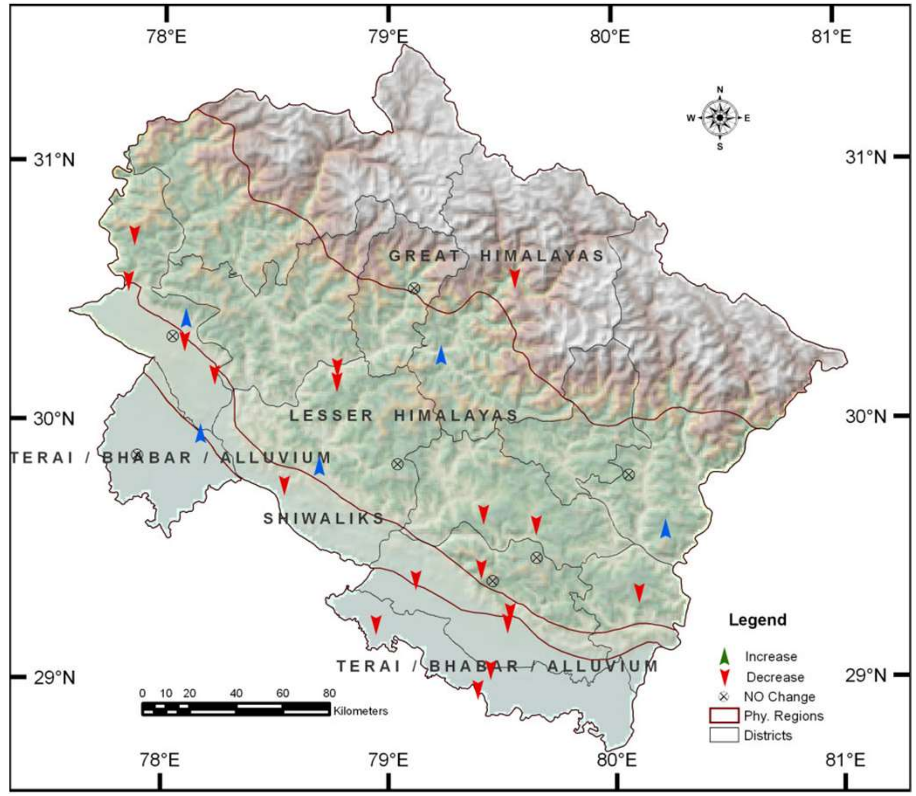
Annual RF 1902-64



Annual RF 1965-80



Monsoon RF 1902-64



Monsoon RF 1965-80

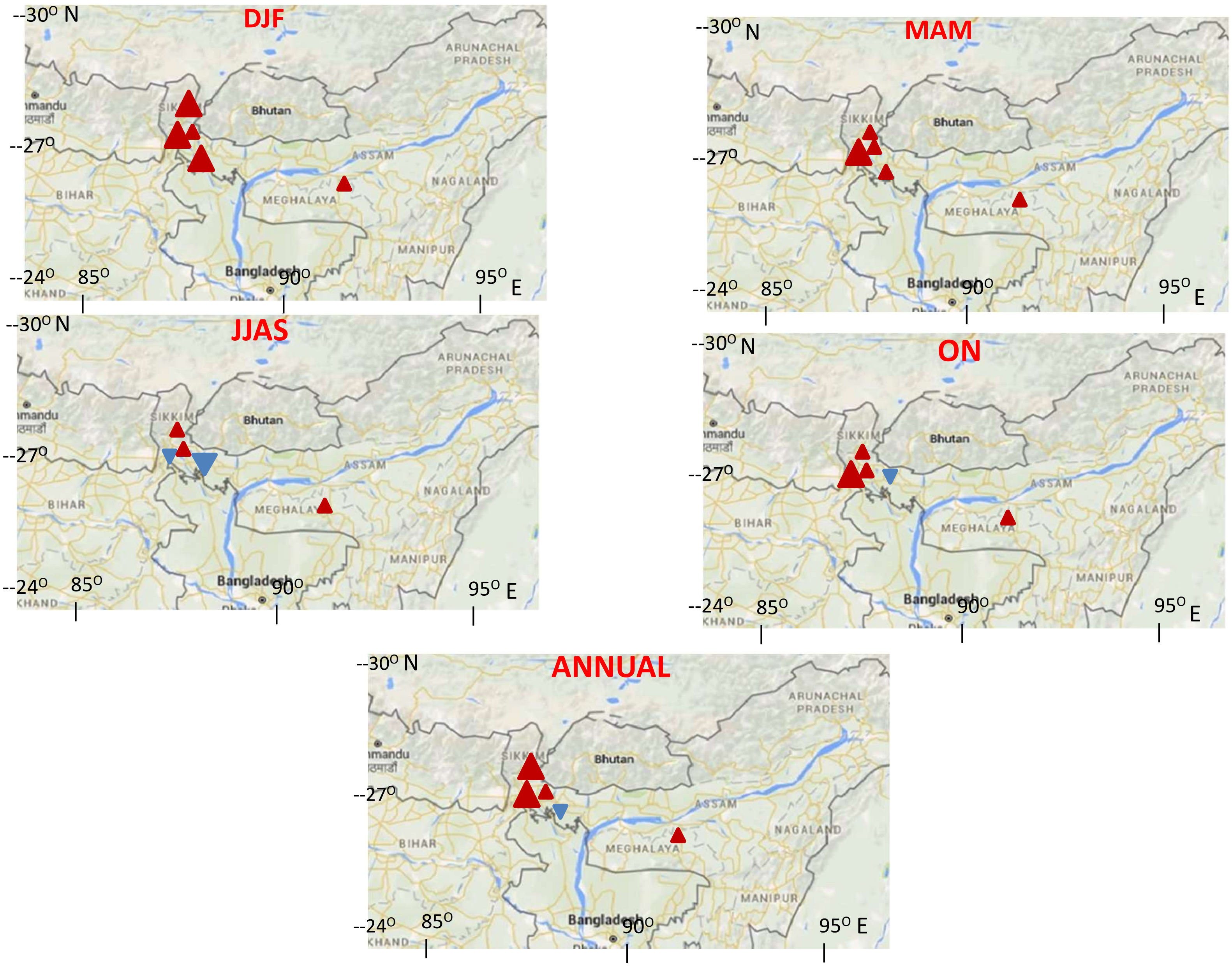
Conclusions

Rainfall has decreased in the Indian Himalayas lying in Uttarakhand State during last century as a sudden shift, rather than gradual trend. The most probable year of change in annual as well as monsoon rainfall is 1964. The period 1902–1964 shows mostly an increasing trend, which reversed during 1965–1980. This pattern in rainfall is most conspicuous over the Shivaliks and southern part of the Lesser Himalayas. Rainfall over the Himalayan region does not correlate well with its neighbouring counterparts, i.e. in the plains, particularly after the late sixties.

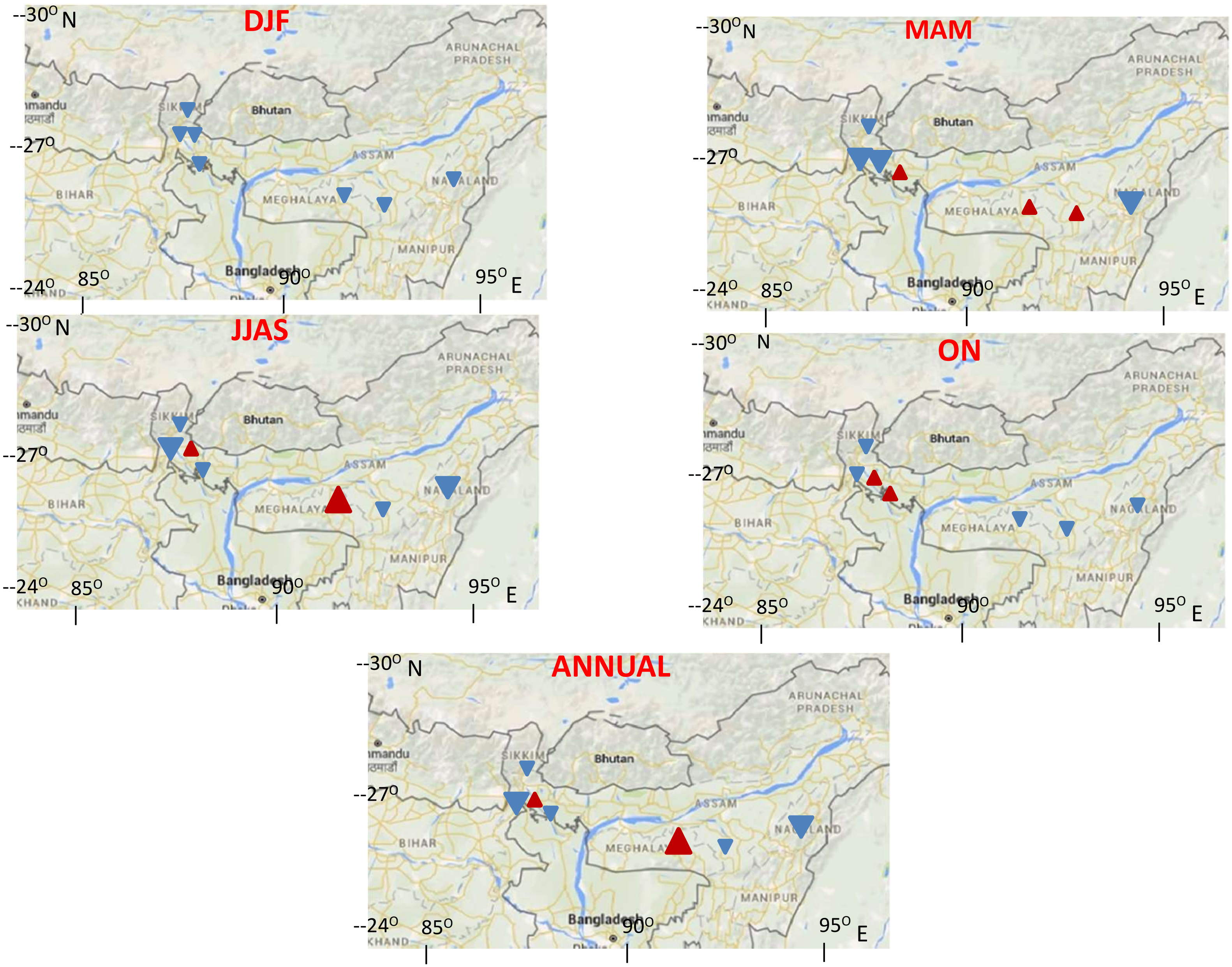
Northeast Himalayan Stations

S.No.	Station	State	Latitude	Longitude	Altitude (M)	Rainfall	Temp.
1	Gangtok	Sikkim	27^0 20’	88^0 40’	1650	1966-2016	1966-2016
2	Darjeeling	W.B.	27^0 03’	88^0 16’	2128	1971-2002	1901-2016
3	Kalimpong	W.B.	27^0 04’	88^0 20’	1209	1922-2002	1920-2000
4	Jalpaiguri	W.B.	26^0 32’	88^0 40’	83	1901-2002	1901-2000
5	Haflong	Assam	25^0 10’	93^0 01’	682	1901-2000	--
6	Cherrapunji	Meghalaya	25^0 15’	91^0 44’	1313	1901-2004	1901-2000
7	Kohima	Nagaland	25^0 38’	94^0 10’	1406	1901-1998	--

Long-term trends (trend/100 yrs.) in mean temperature over eastern Himalaya

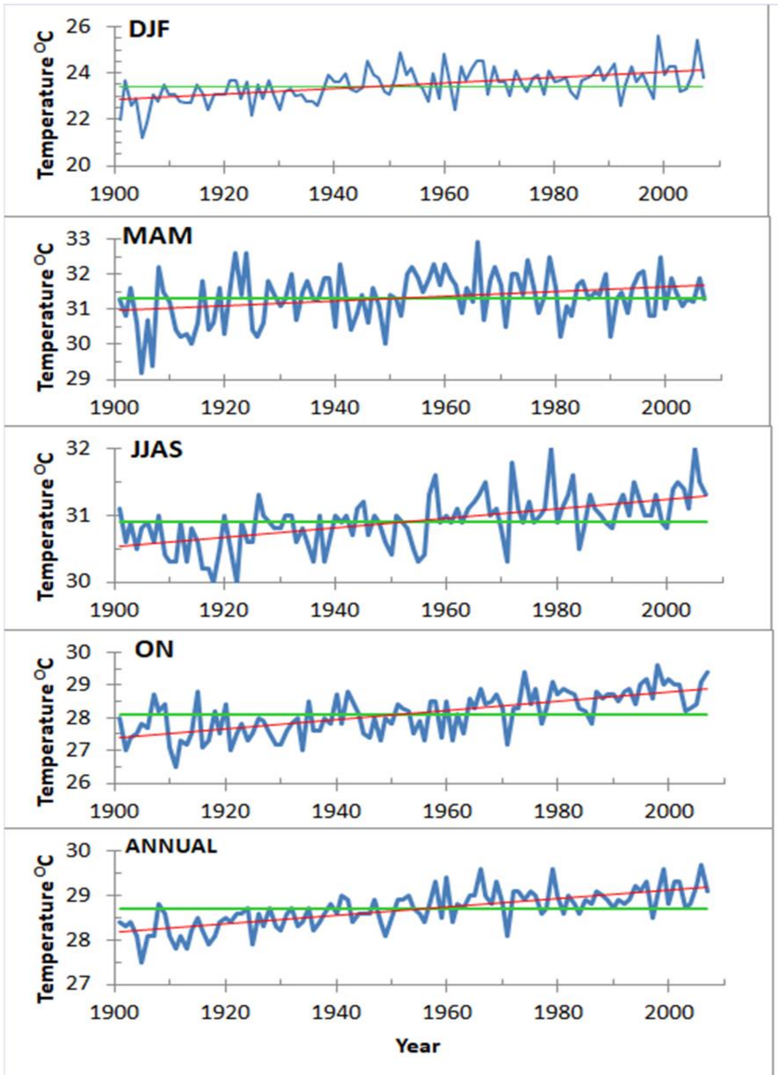


Long-term trends (trend/100 yrs.) in seasonal rainfall over eastern Himalaya

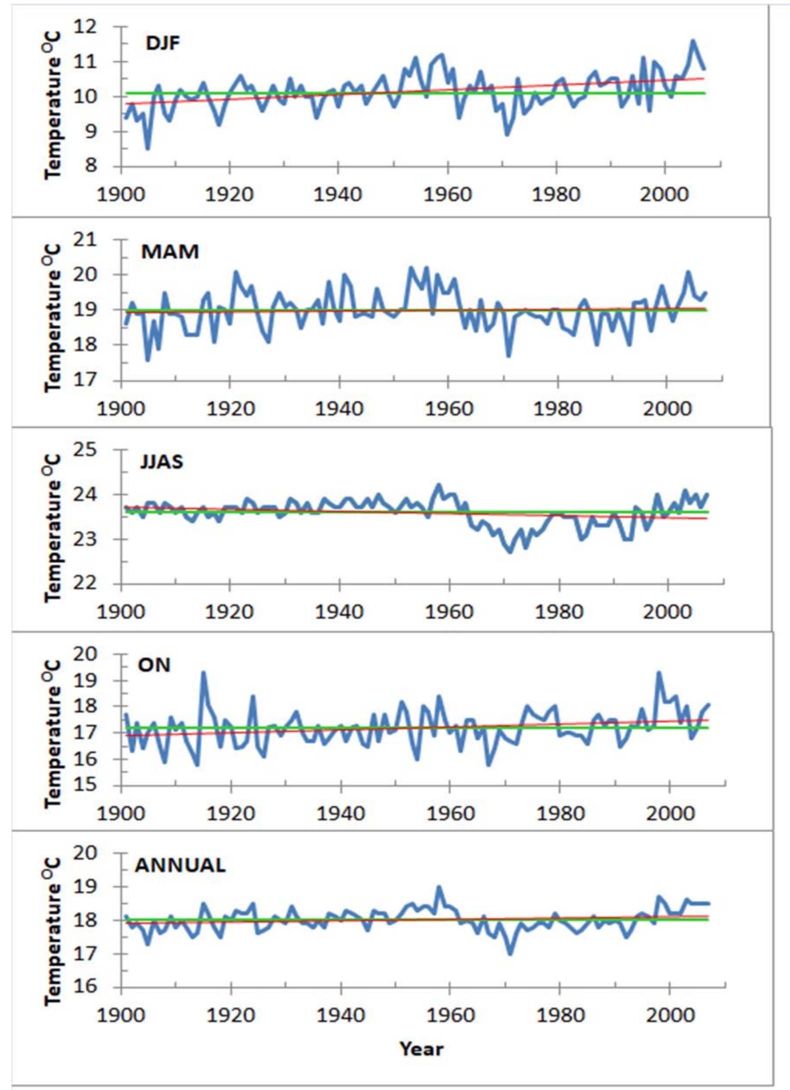


Northeast India temperature for the period 1901-2007

Maximum Temperature

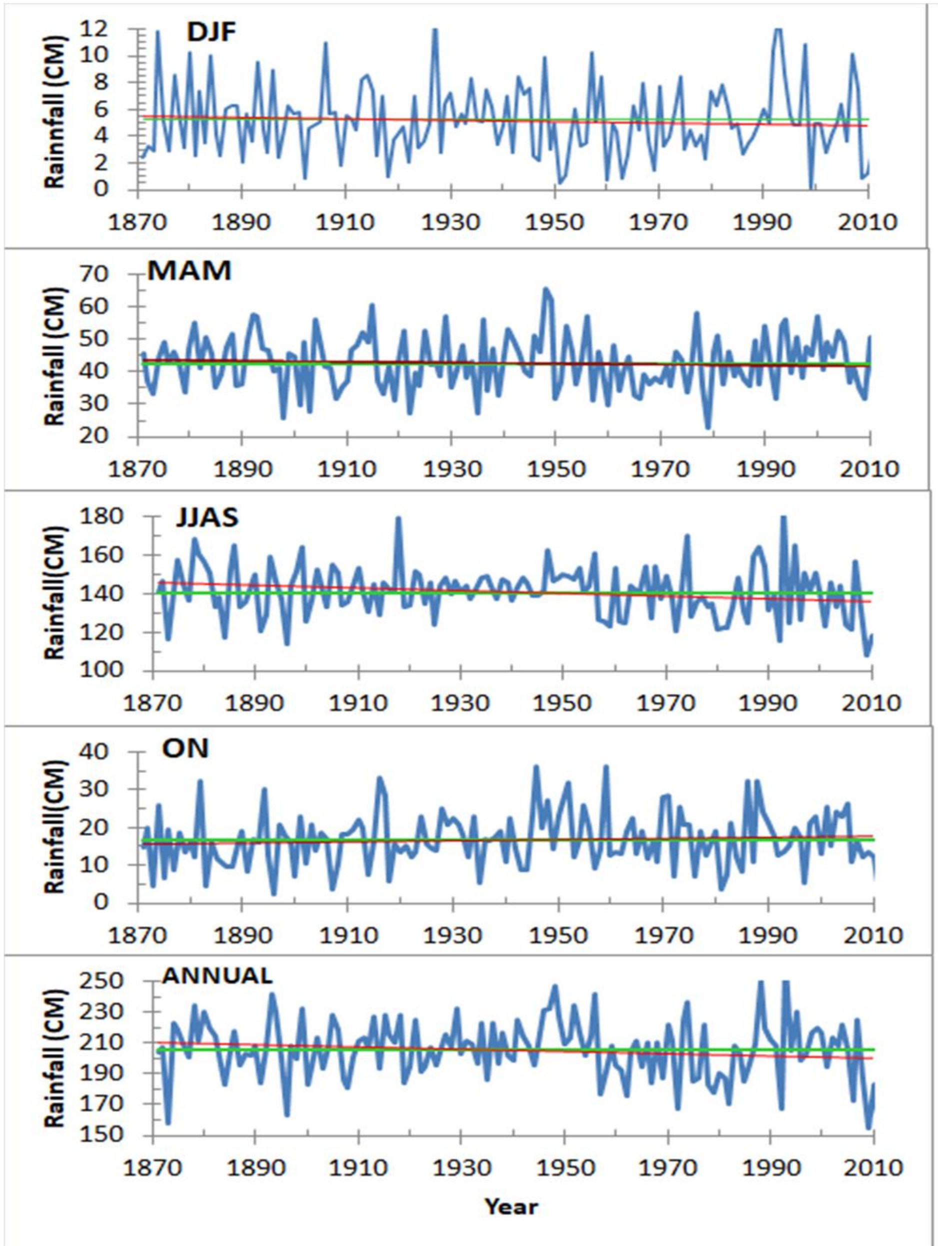


Minimum Temperature



Based on IITM data (freely available at www.tropmet.res.in).

Northeast India Rainfall for the period 1901-2007



Based on IITM data (freely available at www.tropmet.res.in)

Dendroclimatic Reconstructions over Himalaya

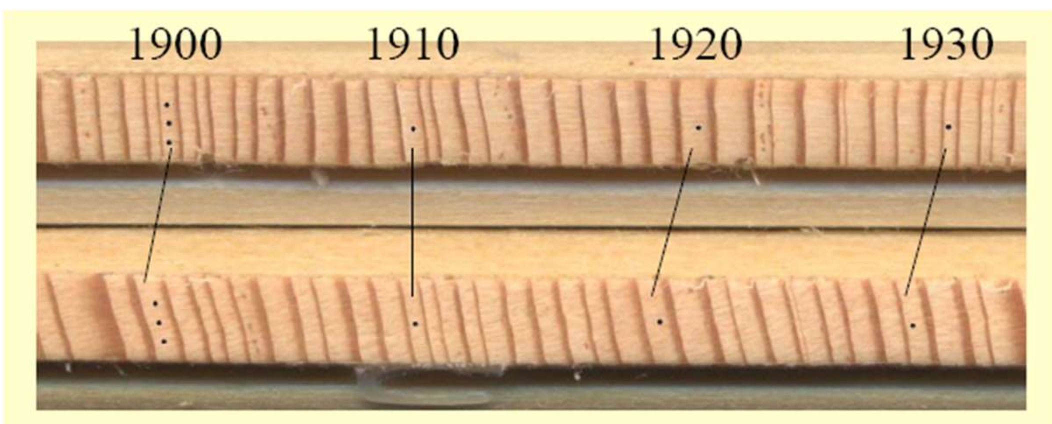
- ***IITM Project:***
- **Development of a Regional Tree-Ring Data Network to study the Past Climatic Variations on Decadal to Century times scales, over Monsoon Asia.**

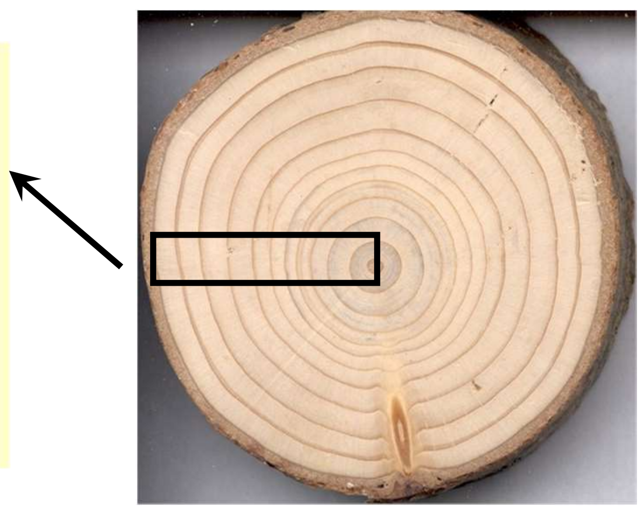
Tree-ring measurement system at IITM, Pune

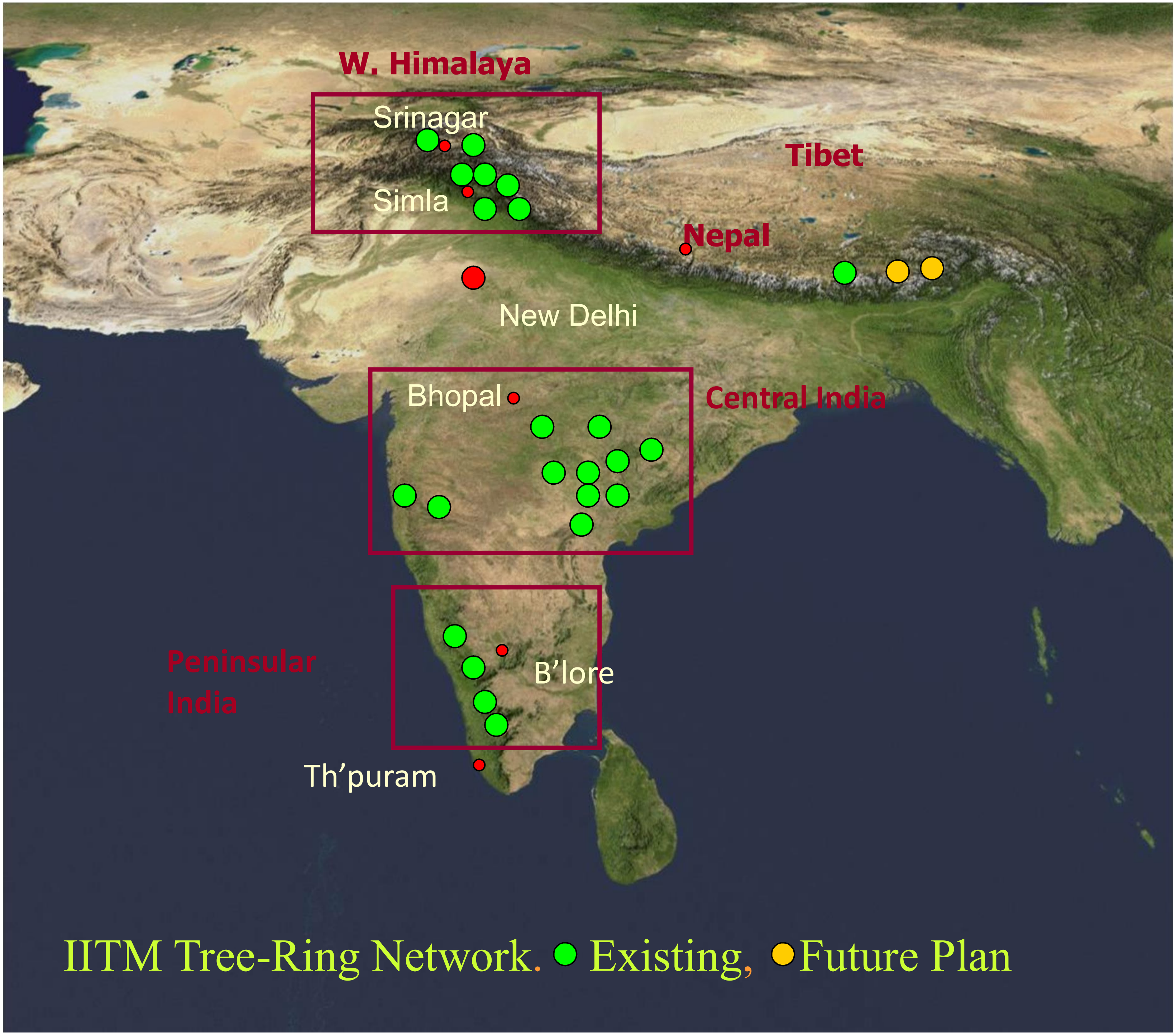
Tree growth is frequently affected by variations in climate. Yearly sequences of favorable and unfavorable climate are faithfully recorded by the sequence of wide and narrow rings in larger number of trees.

Advantages of using tree rings

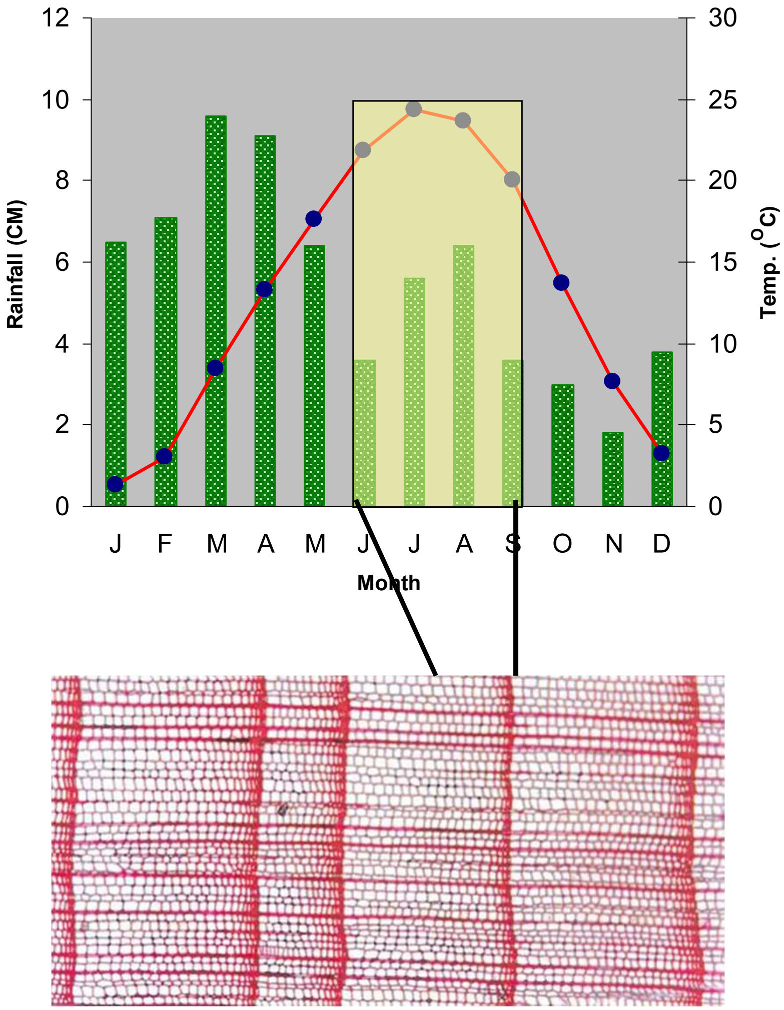
- Tree rings are annually resolved
- A calendar year can be assigned to each ring
- Show a continuous record
- Trees have widespread distribution





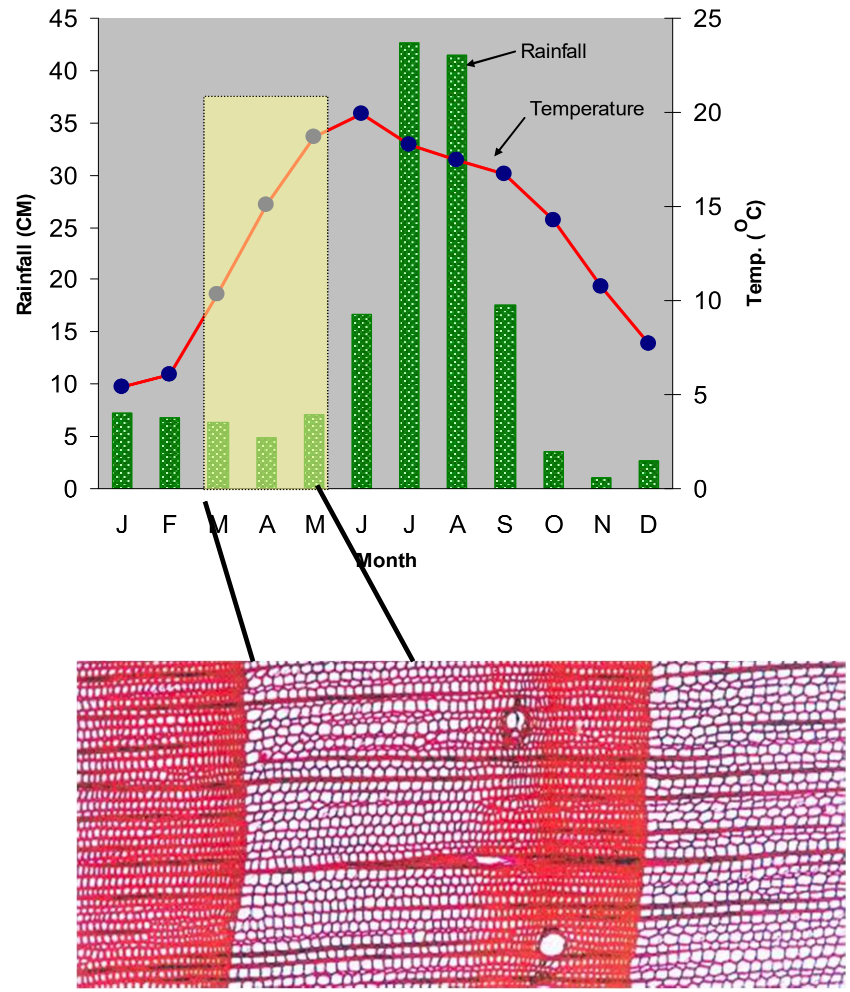

W. Himalaya
Srinagar
Simla
Tibet
Nepal
New Delhi
Bhopal
Central India
Peninsular India
B'lore
Th'puram
IITM Tree-Ring Network. Existing, Future Plan

Kashmir Response



Abies pindraw

Himachal Response



Cedrus deodara

Response function analysis (Monthly) showing response function elements significant at +% level. (● *negative relationship; + positive relationship)*

Kashmir valley Middle Altitude (Northern Latitudes)

	Temperature													Precipitation												
ID	-O	-N	-D	J	F	M	A	M	J	J	A	S	O	-O	-N	-D	J	F	M	A	M	J	J	A	S	O
PHAAP		+	+			+		●	●	●						+	+		+	+	+	+	+	+	+	
PHAPS	+	+						●	●	●	●	●					+		+		+		+	+	+	●
GULAP		+		●	+	+			●	●	●	●								●	+	+	+			●
PARCD					+				●	●		●									+	+	+	+	+	
KNZAP	+	●						●	●		●	●								●	+		+	+	+	

Himachal & Uttarakhand Middle Altitude

	Temperature													Precipitation												
ID	-O	-N	-D	J	F	M	A	M	J	J	A	S	O	-O	-N	-D	J	F	M	A	M	J	J	A	S	O
MNLCD		●				●	●	●					+		+	+				+	+			●		●
KUFCD		●	●			●	●	●			+		+					+	+	+	+	+		●		
KANCD						●	●	●	●	●	+		+		+			+		+	+			●		
NARCD				●	+		●	●							●				+	+				●	●	+
NARAP						●	●	●						●					+	+	+					+
NARPS						●	●	●	●	●			+		+	+			+	+				●	+	
GAHAP	+	●					●	●		●	+		+						+	+	+	+		●		+
GAHPS	+		●			●	●	●		●	+		+						+	+		+	+	●		+
DHAPS			+			●	●	●	●		+	+								+	+		+			

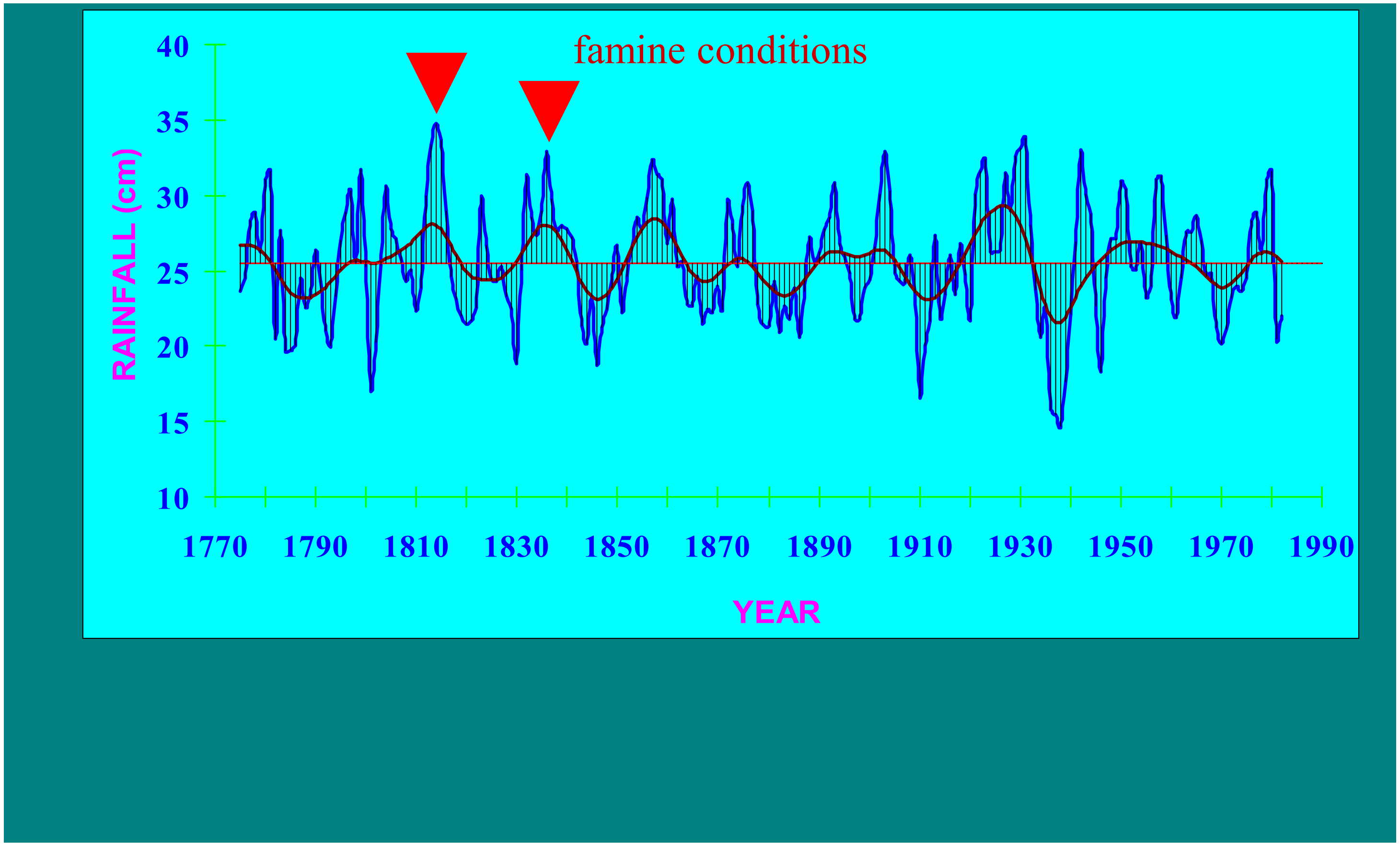
Himacha & Uttarakhanda High Altitude, Near glaciears

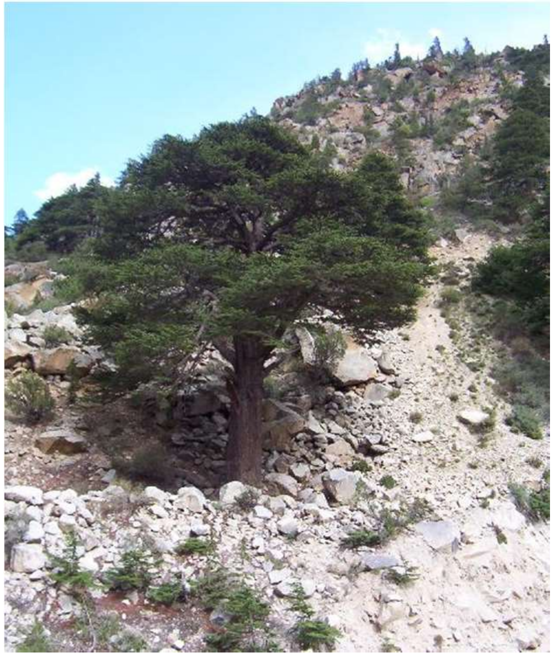
	Temperature													Precipitation												
ID	-O	-N	-D	J	F	M	A	M	J	J	A	S	O	-O	-N	-D	J	F	M	A	M	J	J	A	S	O
KND	+	+	+	+			●	●					+	●	●				+			●		+		+
KAL		+	+	+	+	●	●			+			●	+	●		+		●	+	+					●
SAN		+	+	+	+					●	●		+			●	+		●	+	+	●			●	
KHO	+	+	+	+	+		+		●	●				+		●			+		+		●	●		
KOT	+	+	+	+	+		●											+		+				●	●	
HAM	+	+		+	+	●			●			+		●	+				+				●			
KNG	+	+	+	+	+			●				●	+		+	●	●		+		+				●	+

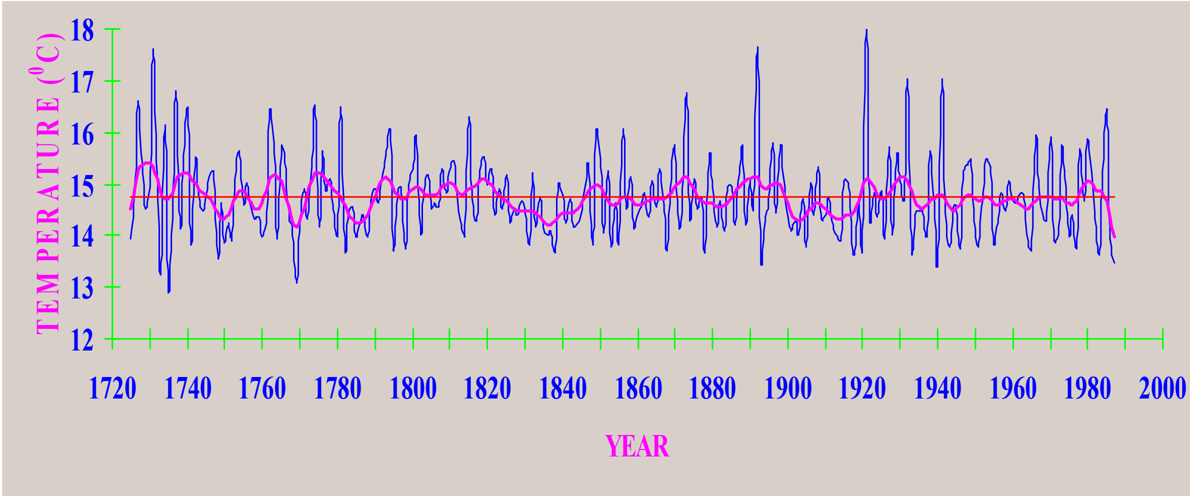
Kashmir tree-ring Summer (May-Sept) Precipitation Reconstruction

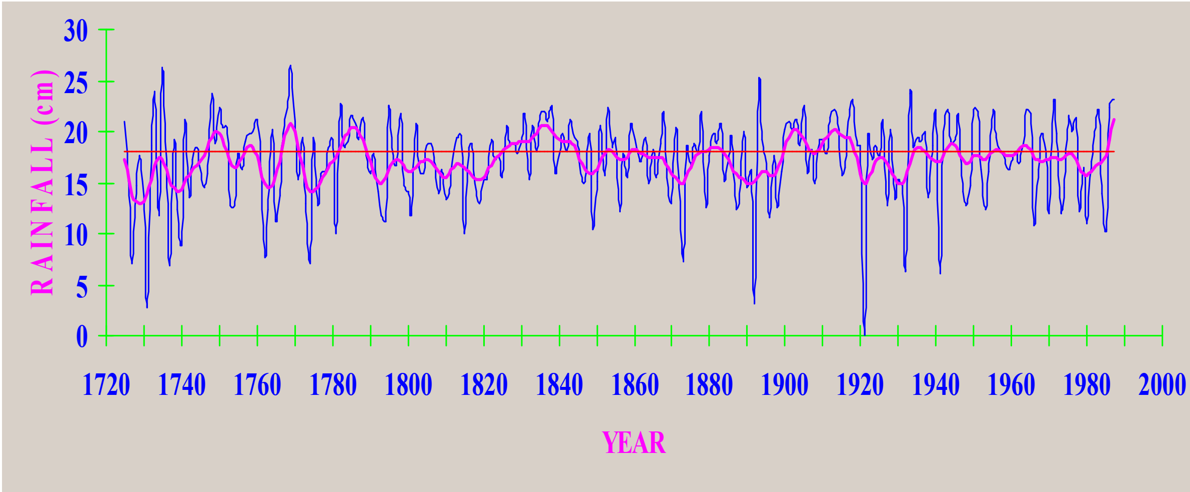
(Borgaonkar *et al.* 1994)

Bamzai (1962) and Koul, (1978) reported famine conditions during 1813-1815 and 1833-37. Crop yield was very poor due to heavy rains.



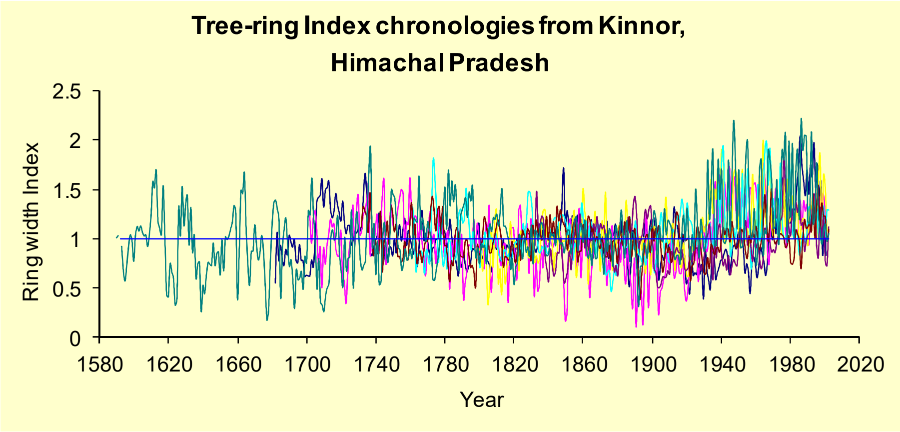


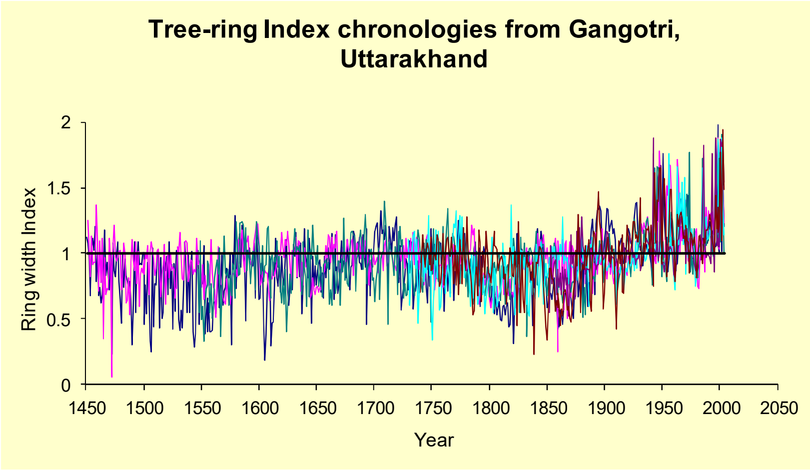




Western Himalaya Summer Climate (MAM) Reconstruction from multi-species tree-ring width chronologies since A.D. 1725 (Pant *et al.* 1998)

High altitude tree-ring chronologies from Western Himalaya



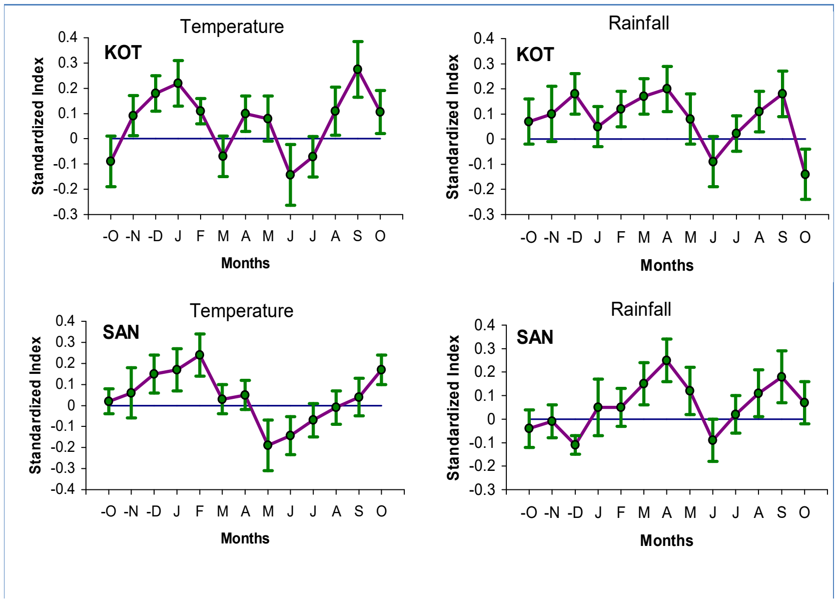


Kinnor, W.H. India, 3200 M amsl

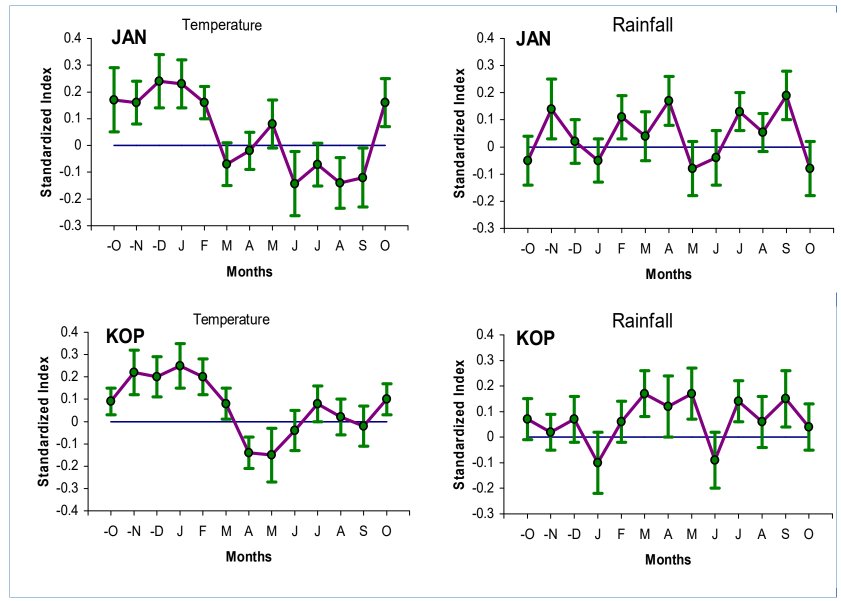
Gangotri, W.H. India, 3000 M amsl

Tree growth climate relationship

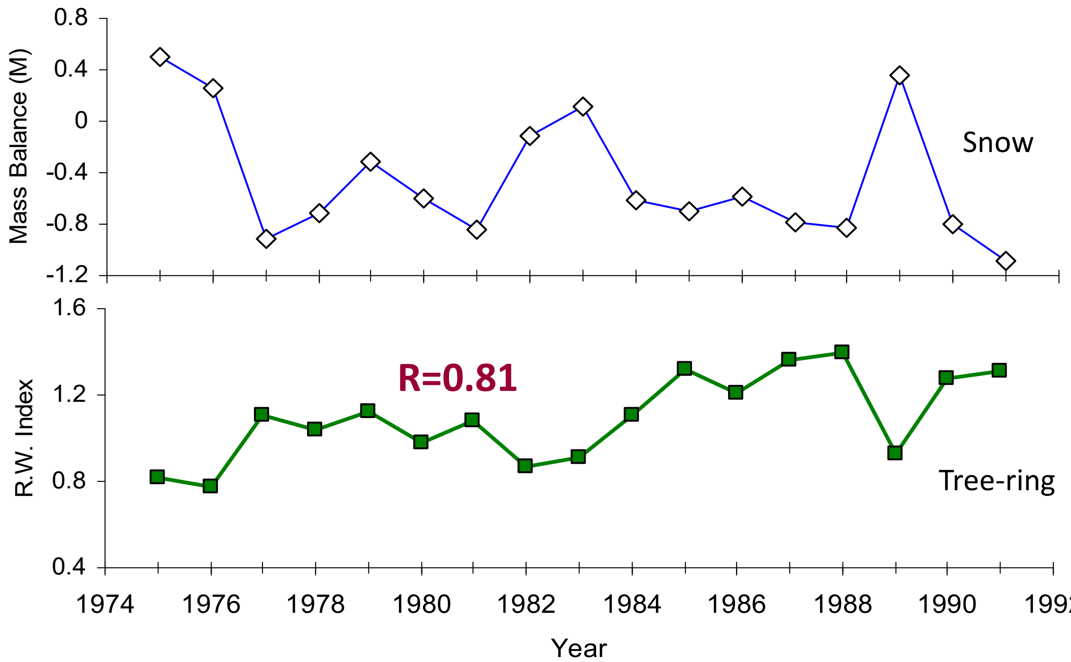
Kinnor, Himachal Pradesh

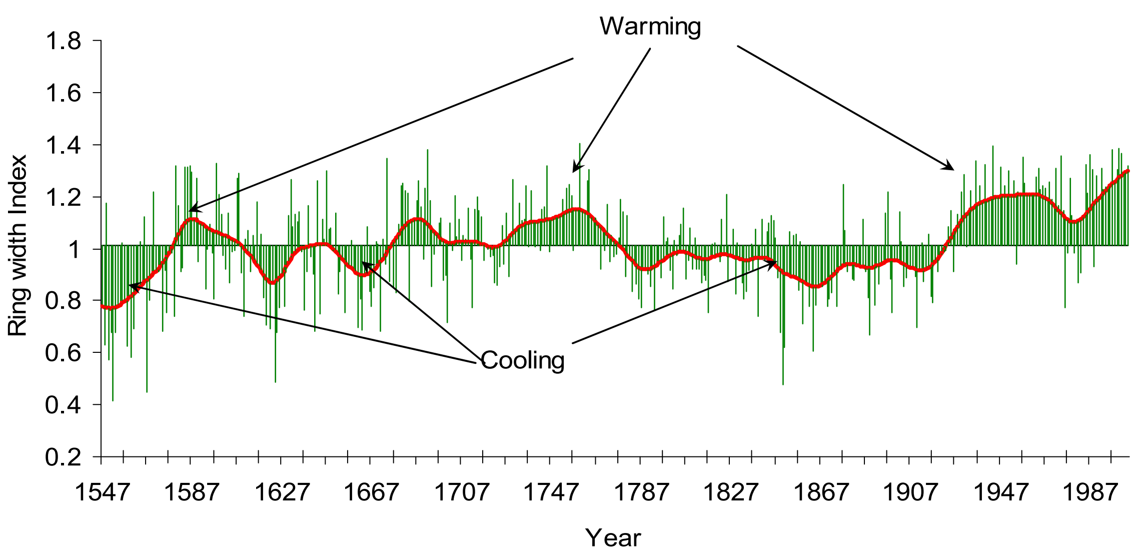


Gangotri, Uttarakhand

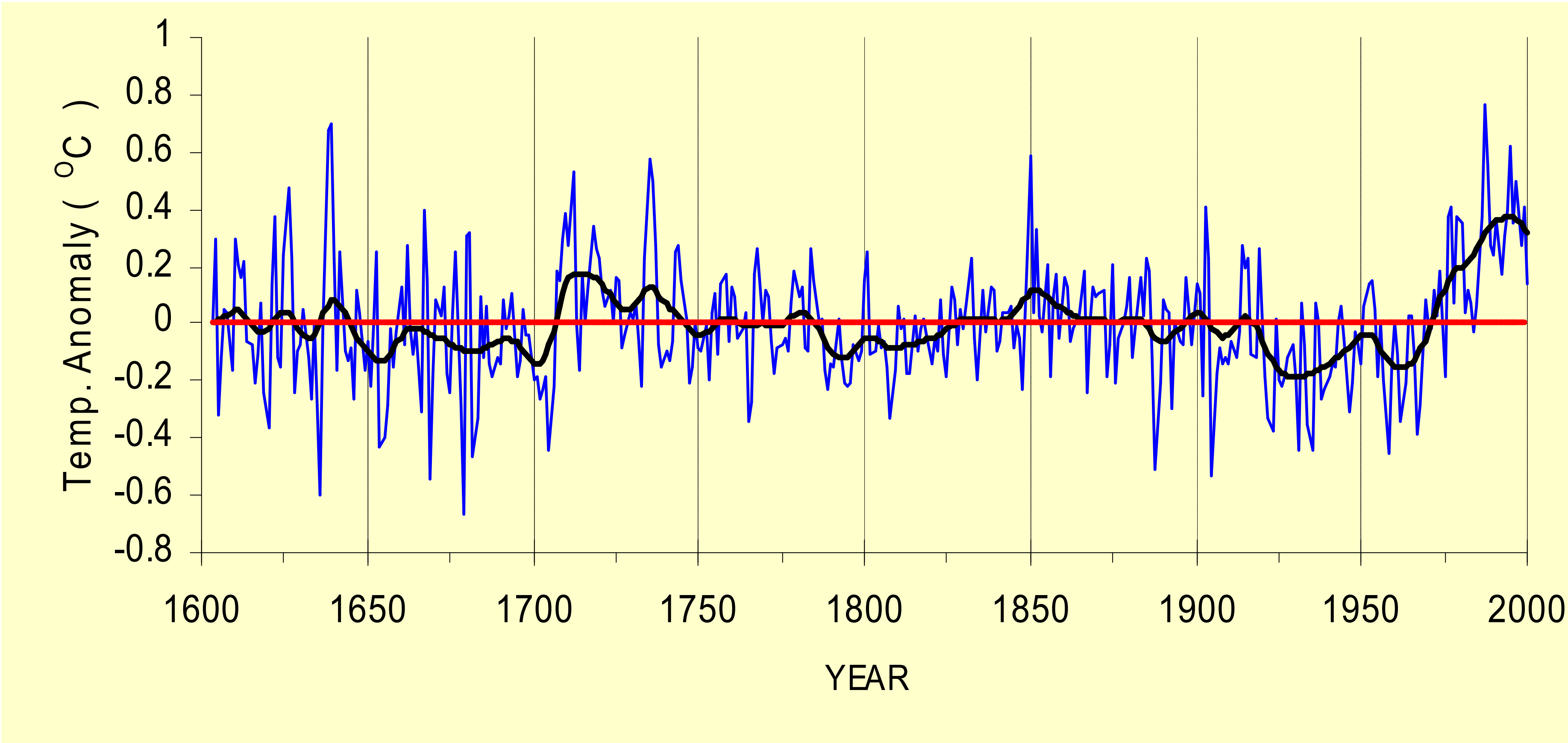


Response functions of tree-ring chronologies from Kinnor, Himachal Pradesh and Gangotri , Uttarakhand using monthly temperature and rainfall anomalies of Western Himalaya. Error bars are 95% confidence intervals.



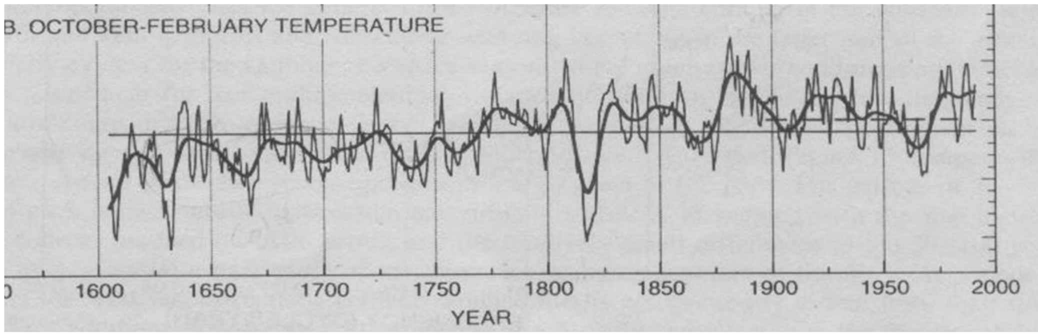


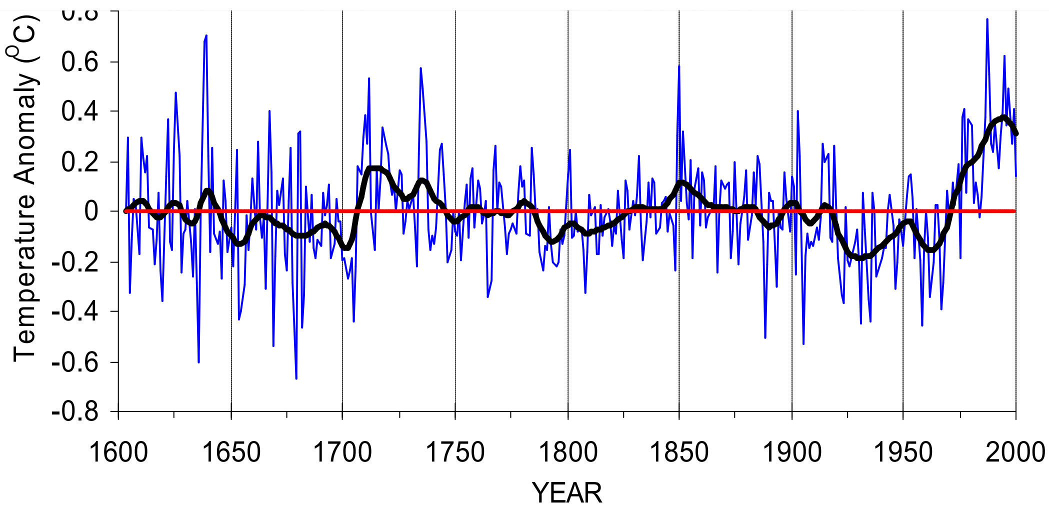
458 years (A.D. 1547-2004) long tree-ring index chronology of high altitude Himalayan cedar (*Cedrus deodara* D. Don.) from Western Himalaya. Smooth red line is 30 years cubic spline filter. Suppressed (cooling) and released (warming) growth patterns in tree-ring chronology have also been observed to be well related to the past glacial fluctuation records of the region (***Borgaonkar et al* 2009**)



Reconstructed winter (ONDJF) temperature over Western Himalaya since A.D.1603. Smooth line is cubic spline curve with wavelength equal to 20 years.

Nepal Temp. (Oct-Feb); Cook *et al.* (2003)

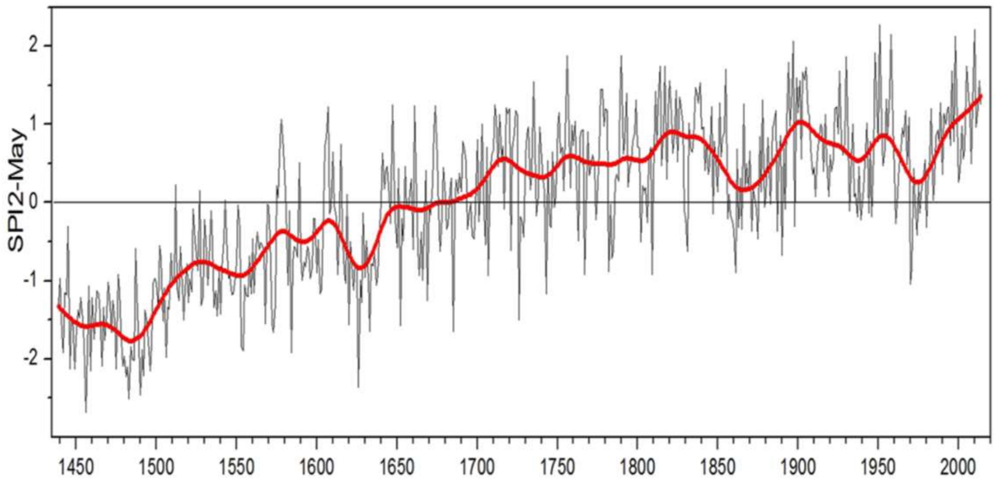




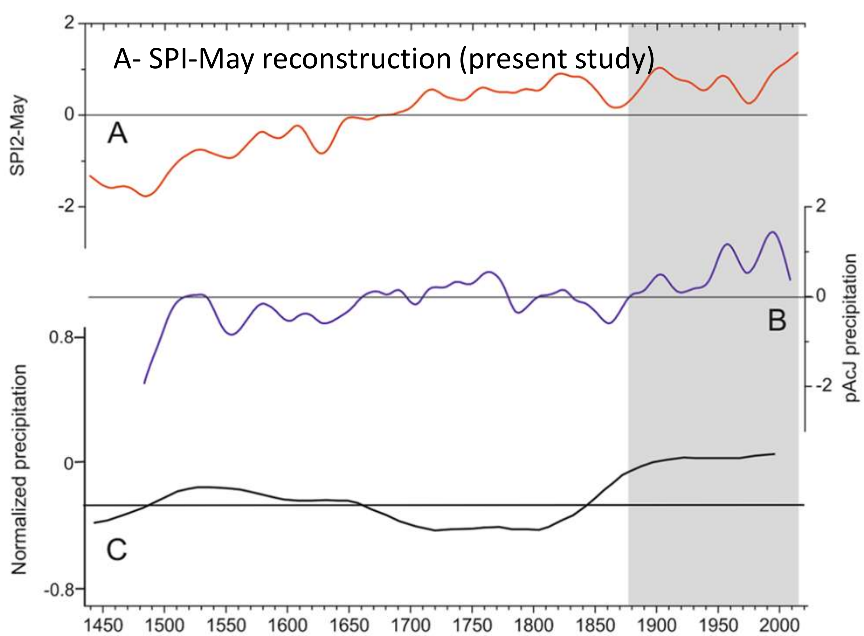
W.H. Temp. (Oct-Feb); work in progress

Recent Wetting and Glacier Expansion in the Northwest Himalaya and Karakoram

(Yadav *et al.* 2017)



Standardize Precipitation Index (SPI) of May reconstructed series (A.D. 1439–2014). The thick line superimposed on the reconstruction is 40-year low pass filter.



Tree-ring-based hydro-climatic records from the northwest (NW) Himalaya, India and Karakoram, northern Pakistan showing increased wetting in the 20th century and recent decades.

A- SPI-May reconstruction (present study),

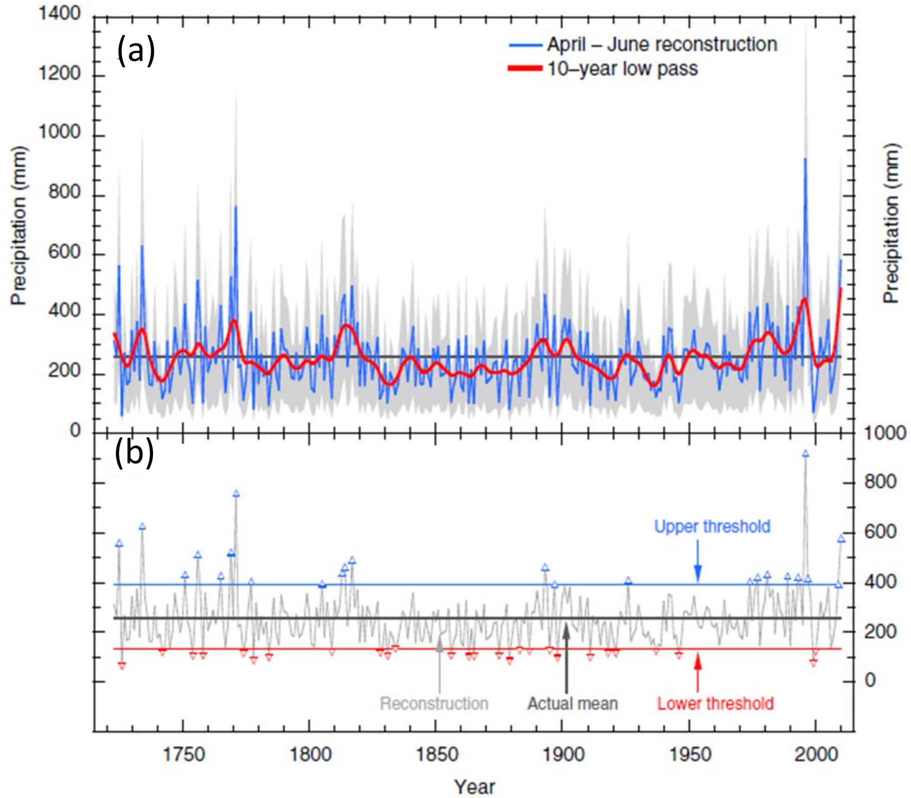
B-tree-ring-based previous year August to current year July (pAcJ) precipitation for cold-arid Lahaul, NW Himalaya,

C- tree-ring δ18O based precipitation for Karakoram, northern Pakistan

the data in A and B were normalized relative to the mean and standard deviation of the length of respective series and 40-year spline filtered;

an increased wetting could be augmenting the positive glacier mass balance in the NW Himalaya and Karakoram.

Precipitation reconstruction for the Lidder Valley, Kashmir Himalaya using tree-rings of *Cedrus deodara* (Shah *et al.* 2018)

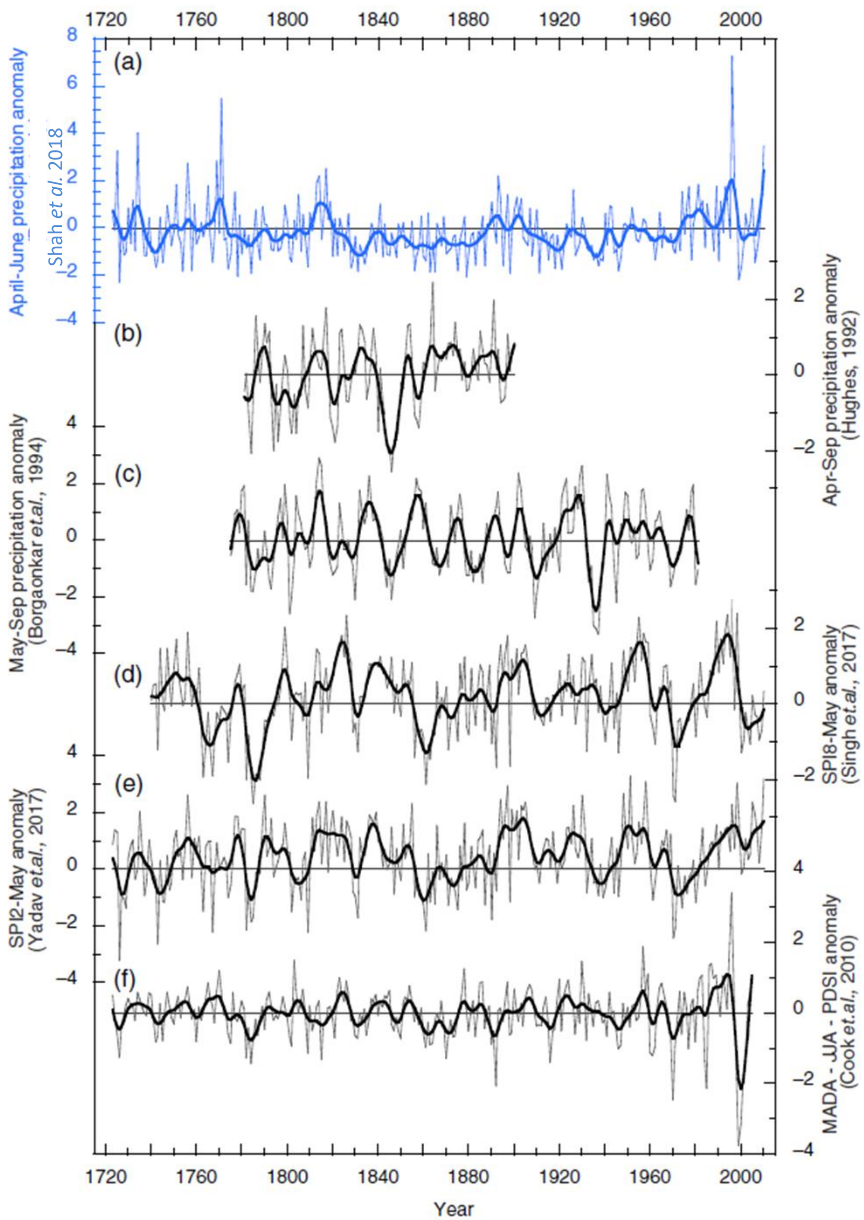


(a) Reconstructed April–June precipitation for the Lidder Valley, Kashmir spanning 1723–2010 C.E. along with 10-year low-pass filtered smooth and 90% MEBoot uncertainties (shaded area). The long-term mean (259 mm) based on actual data is indicated by thin black line

(b) Reconstruction marked for extreme dry and wet years based on lower threshold (tenth percentile) and upper threshold (90th percentile).

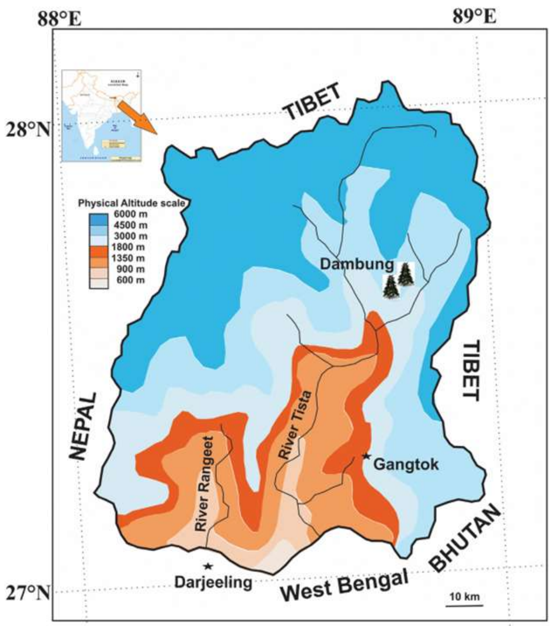
Extreme dry and wet years in reconstructed April-June precipitation
based on lower threshold (10th percentile) and upper threshold (90th percentile).

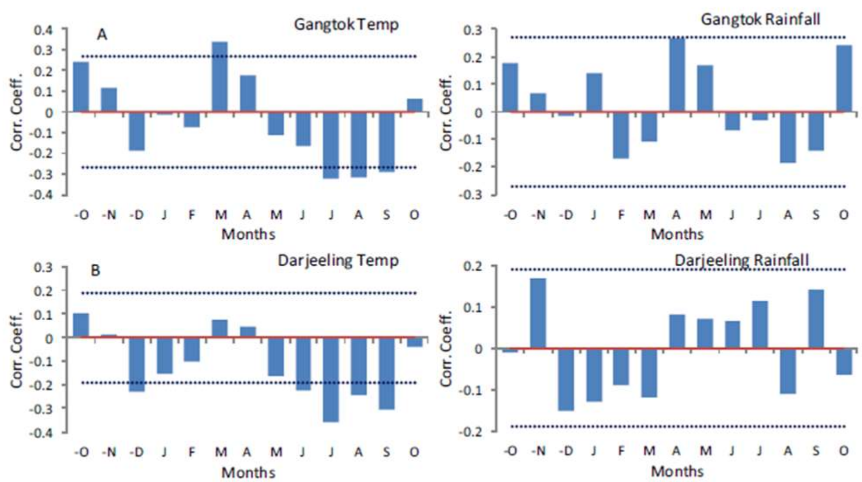
Extreme dry years based on lower threshold (10th percentile)	Extreme wet years based on upper threshold (90th percentile)
1726, 1742, 1754, 1758, 1774, 1778, 1784, 1809, 1828, 1831, 1834, 1856, 1863, 1865, 1875, 1879, 1883, 1887, 1895, 1898, 1911, 1918, 1921, 1937, 1946, 1999-2000	1725, 1734, 1751, 1756, 1765, 1769, 1771, 1777, 1805, 1813-1814, 1817, 1893, 1897, 1926, 1974, 1977, 1981, 1989, 1993, 1996-1997, 2009-2010



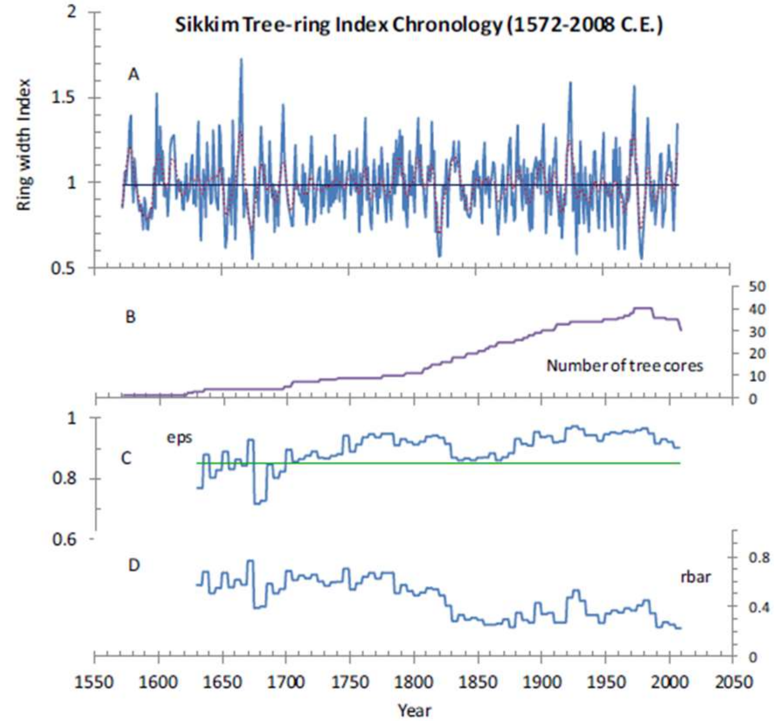
The temporal comparison of tree-ring based various precipitation and drought reconstructions from northwest Himalayan region. The data reference of the each record is given in y-axis of each plot. Thick line in each plot represents 10-year low-pass filter.

Sikkim summer (July-September) temperature reconstruction





Correlation analysis between Sikkim tree-ring chronology and (A) Gangtok Climate (B) Darjeeling Climate.

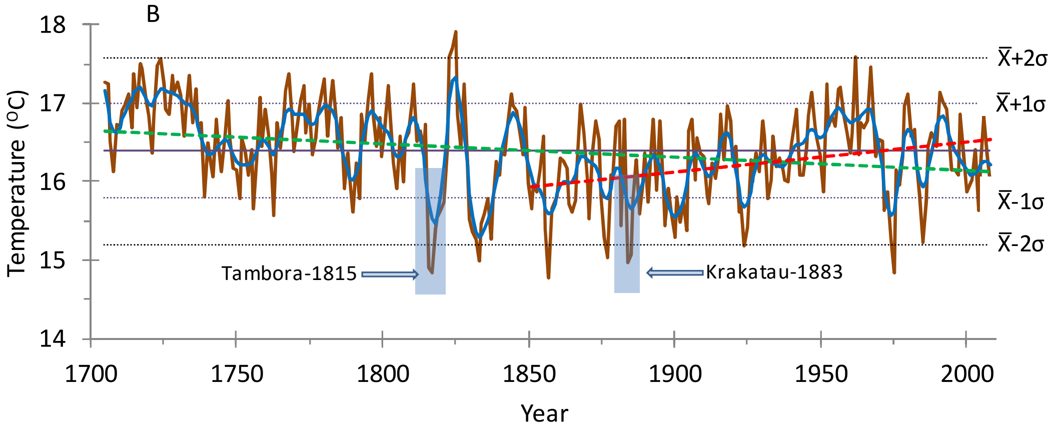


(A) 437-year (1572–2008 C.E.) tree-ring width index chronology of *Tsuga dumosa* (D. Don) from Dambung, Sikkim. Dotted red line is 10-year low pass filter. (B) Sample replication chronology, (C) Running EPS and (D) running RBAR statistics with 10-year windows overlapping of 5-year. Green line in (C) indicates the EPS threshold value of 0.85.

(Borgaonkar *et al.* 2018)

Sikkim summer temperature reconstruction

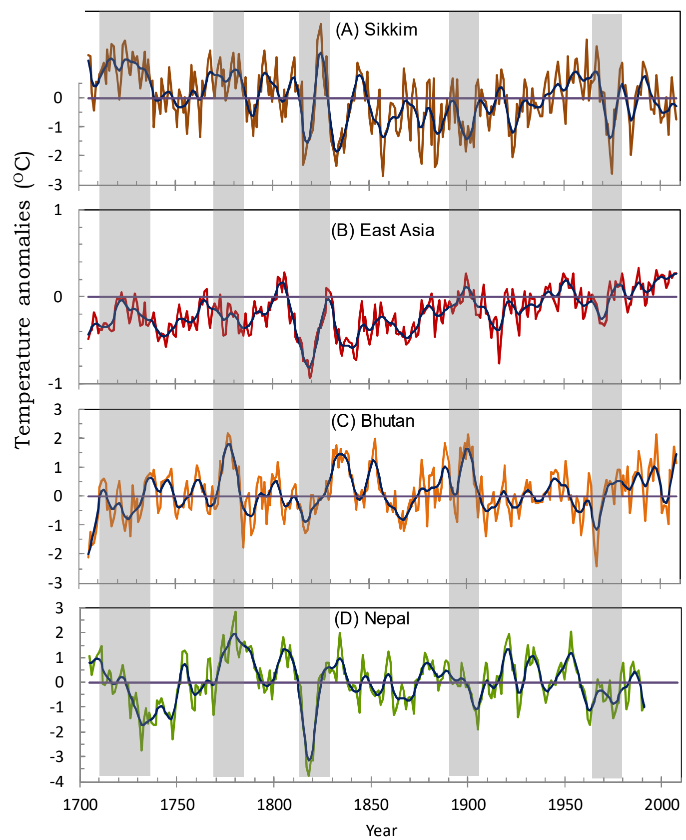
(Borgaonkar *et al.* 2018)



Reconstructed late-summer (July–September) temperature of Sikkim. from 1705–2008 C.E. Green and red dotted lines indicate trend for full reconstructed period and for the period 1850–2008 C.E. respectively.

Extremely warm temperature years (≥ x̄+2σ) : 1724, 1823, 1824, 825,1962
warm periods (≥ x̄+1σ) : 1713-1734, 1823-1827 C.E.

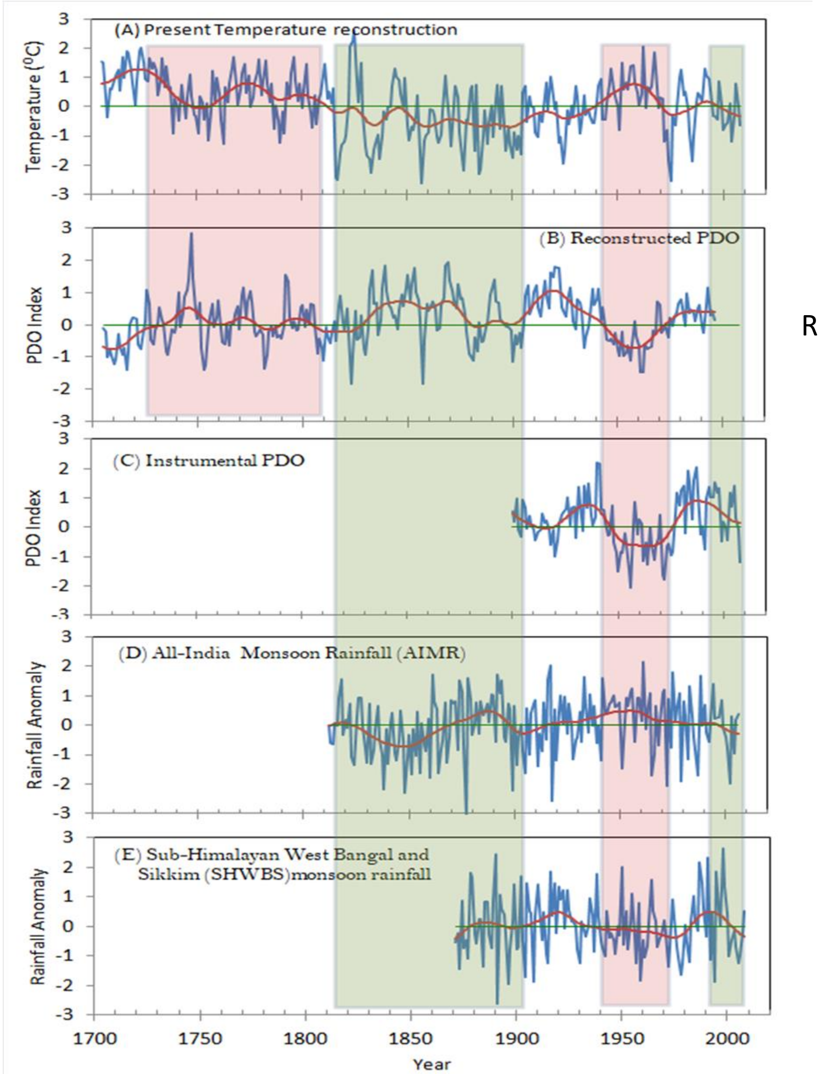
Extremely cold years (≤ x̄-2σ): 1816, 1817, 1833, 1857, 1877, 1884, 1885, 1924, 1975 C.E.,
cold periods (≤ x̄-1σ): 1816-1819, 1831-1837, 1856-1859,1884-87, 1898-1903, 1923-1925, 1973-1975 C.E



(A) Sikkim temperature reconstruction (1705-2008 C.E.)
(B) East Asia reconstruction by Cook *et al*. (2013),
(C) Bhutan reconstruction by Krusic *et al*. (2015)
(D) Nepal by Cook *et al.* (2003).

over the common period. Smooth blue lines indicate 10 years low pass filter

Sikkim summer temperature reconstruction



R = -0.60*** (N=292)

R = -0.54*** (N=109)

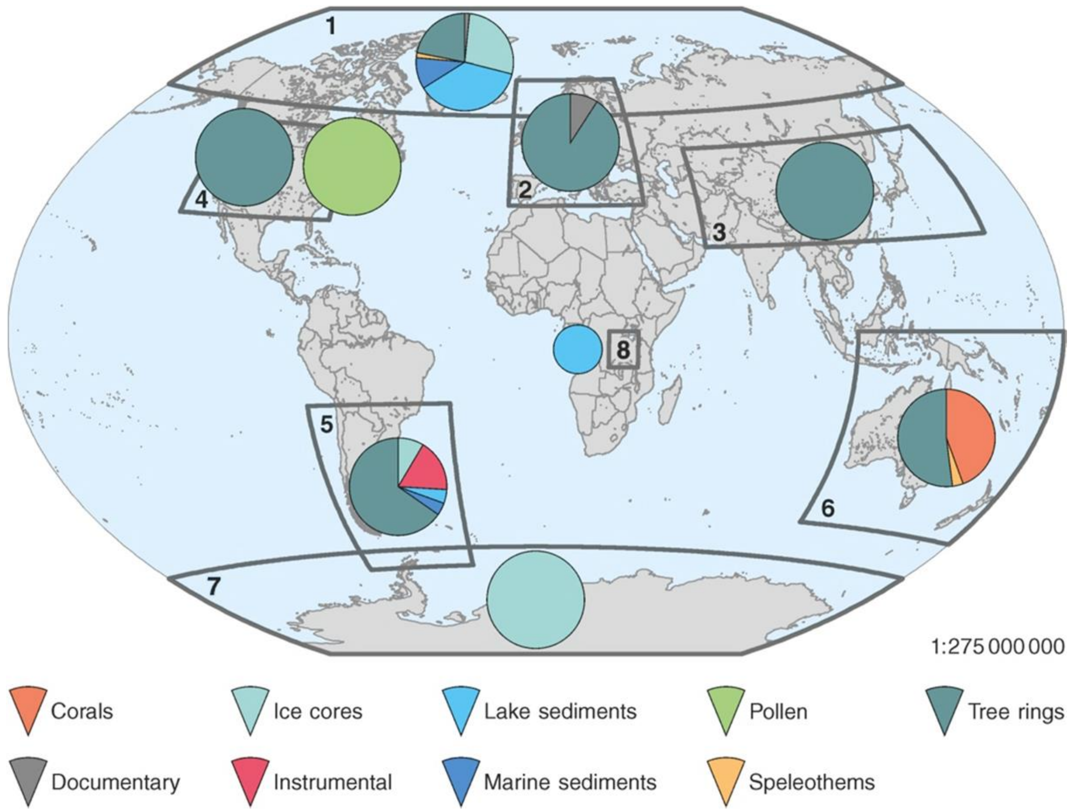
R = +0.32*** (N=194)

R = -0.20* (N=138)

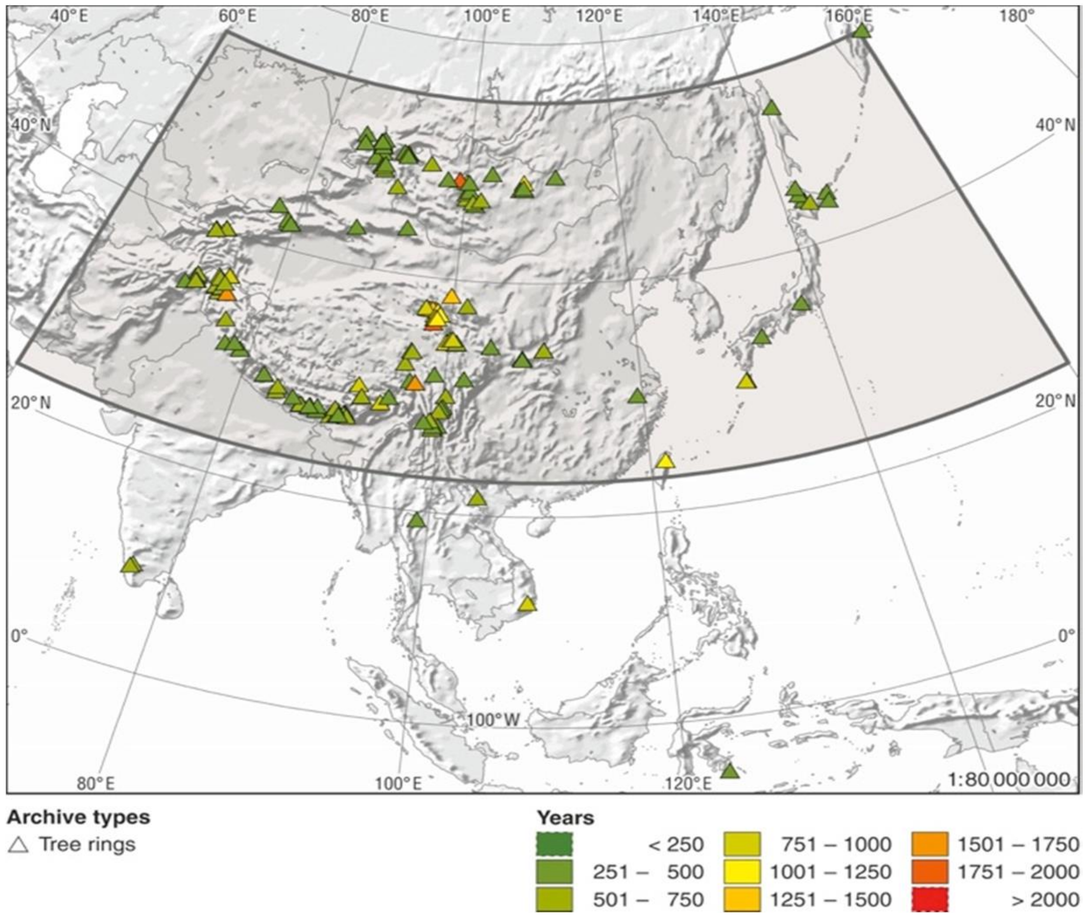
Comparison of reconstructed late-summer temperature (A) with reconstructed PDO index (B), instrumental PDO index (C), longest all India monsoon rainfall (D) and Sub-Himalayan West Bengal and Sikkim (SHWBS) monsoon rainfall (E). Red lines indicate cubic spline curve of 30-year wavelength.

Continental-scale temperature variability during the past two millennia

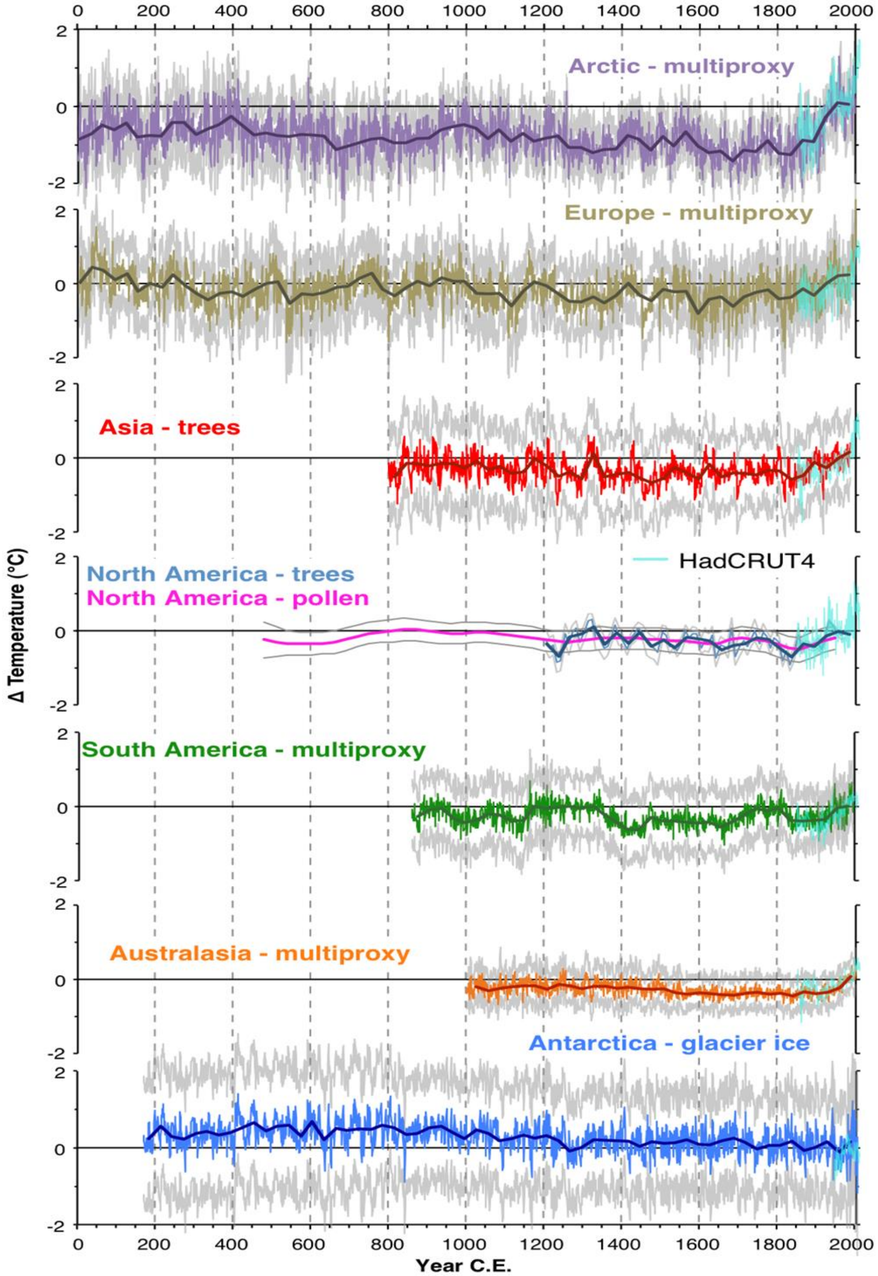
PAGES 2k Consortium



NATURE GEOSCIENCE , VOL 6, MAY 2013



Asia 2k regional domain with locations of tree-ring records used for the temperature reconstruction. Symbol color indicates the length of the record.



Proxy temperature reconstructions for the seven regions of the PAGES 2k Network. Temperature anomalies are relative to the 1961-1990 CE reference period. Grey lines around expected-value estimates indicate uncertainty ranges as defined by each regional group

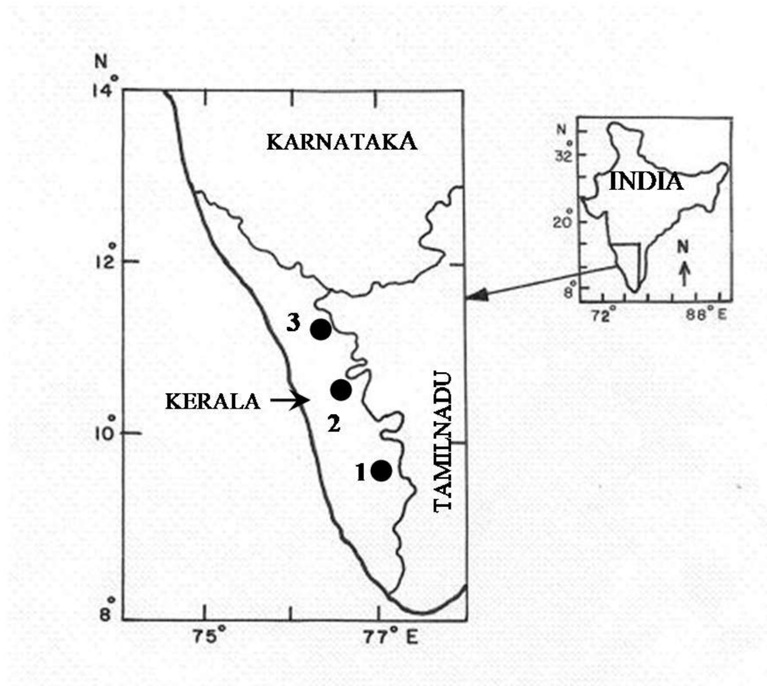
* Nearly all of the regional temperature reconstructions is a long-term cooling trend, which ended late in the nineteenth century.

* No globally synchronous multi-decadal warm or cold intervals that define a worldwide Medieval Warm Period or Little Ice Age, but all reconstructions show generally cold conditions between ad 1580 and 1880, punctuated in some regions by warm decades during the eighteenth century.

Tree-ring Drought Records of Indian Monsoon rainfall since past five centuries.

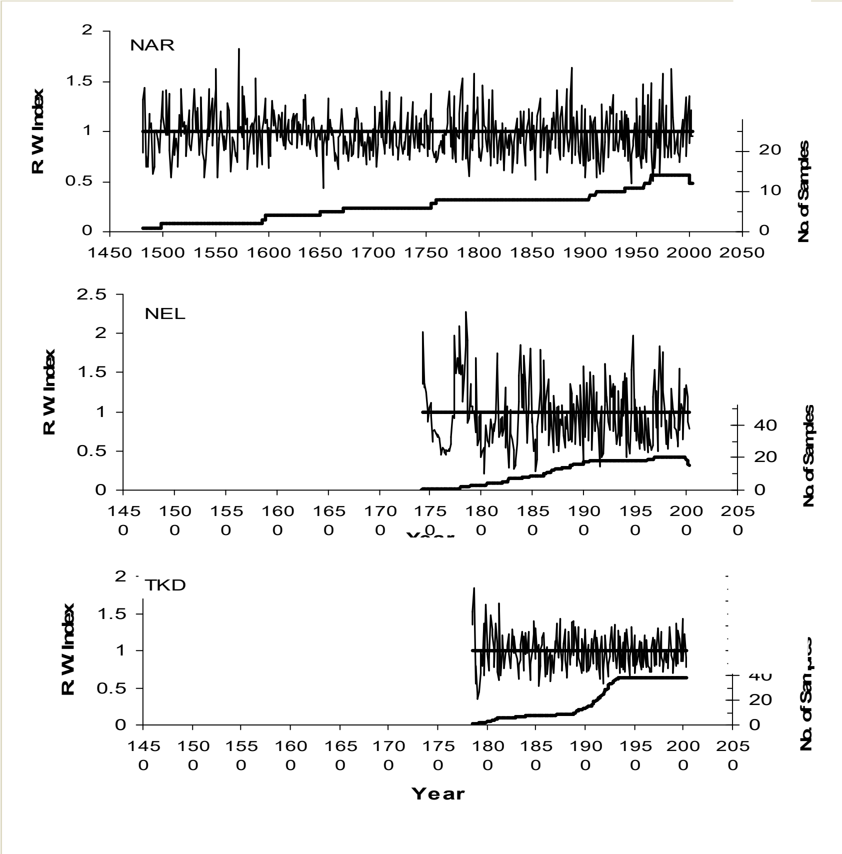
Gaint Teak (Biggest in Asia)

Kappayam, Malayatoor, Kerala, South India (Girth at breast height : 7.2 M)



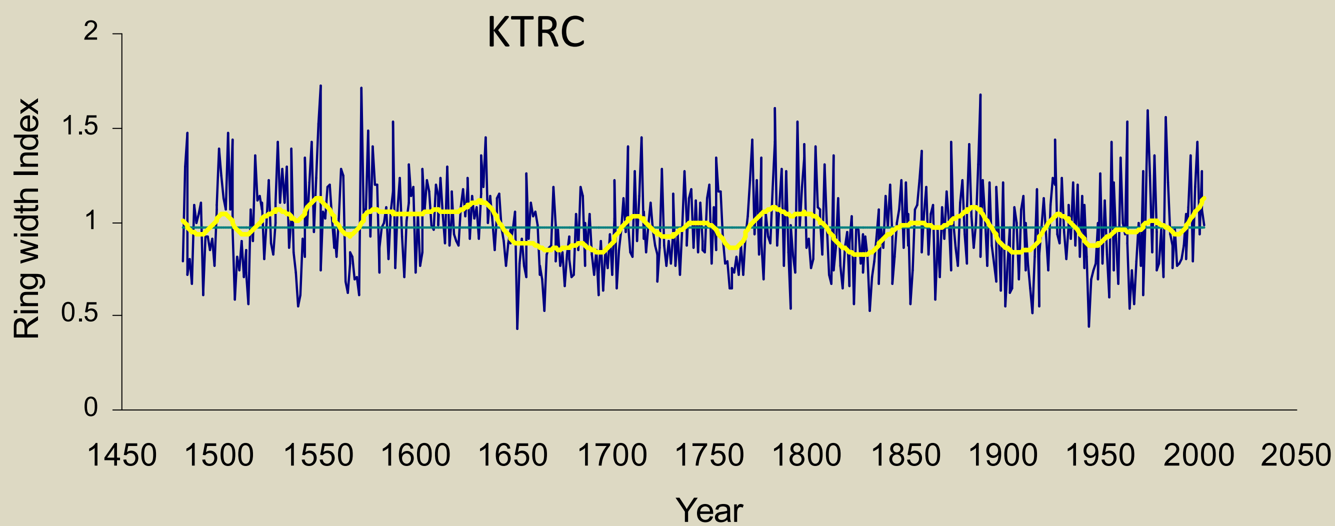
Locations of the Tree-ring sites. 1 : Tekkady (TKD); 2 : Narangathara (NAR); 3 : Nellikooth (NEL).

(Palaeo-3; Borgaonkar *et al*. 2010)

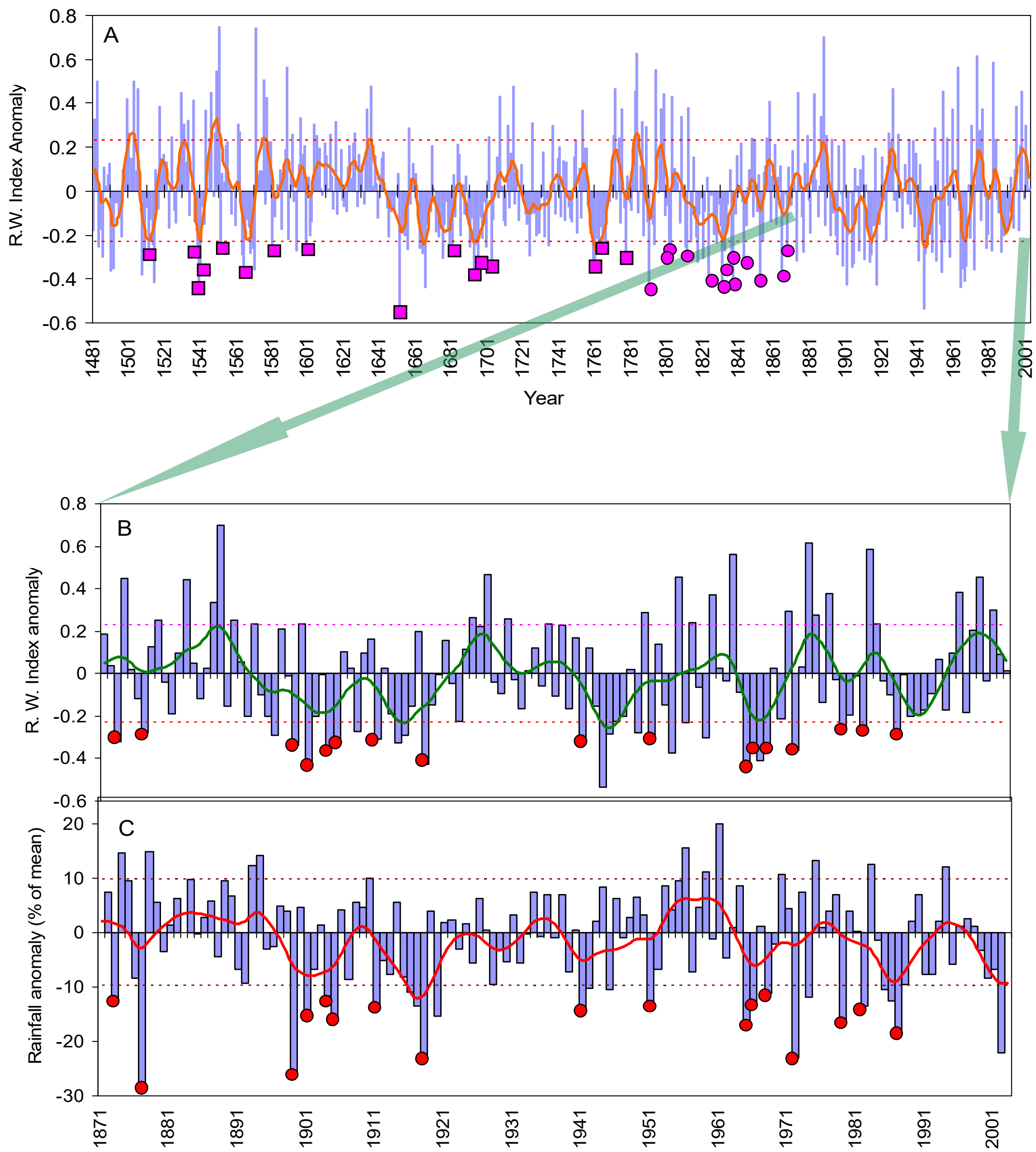


Intercorrelations among the three teak tree-ring chronologies of Kerala, south India. Bold figures of correlation coefficient (R) indicate the correlations after the standardization of tree-ring series. All the correlations are significant at P < .001 over the Common Period 1785-2003 (219 years).

	NAR	NEL	TKD
NAR	1.00	0.33/ **0.45**.	0.45/ **0.64**
NEL	--	1.00	0.55 / **0.57**
TKD	--	--	1.00



Indian teak tree-ring chronology and Indian droughts
(A.D. 1481-2003; 523 Years).



A) Tree-ring width index anomaly of KTRC in relation to long-term mean. Smooth line is 10 year cubic spline fit. Dashed lines in all the figures indicate "Mean± Std.Dev." limit. Magenta circles indicate low growth years occurred during the deficient rainfall (droughts) years associated with the El Nino. Magenta squares are low growth years associated with El Nino years.

(B and C) KTRC and ISMR anomalies respectively during the instrumental period 1871-2003. Red circles in fig. B are low growth years and have one to one correspondence with deficient monsoon rainfall (drought) years associated with El Nino shown as red circles in fig. C.

Summary

- Increasing trends in maximum temperature for all the stations and in all the seasons. Most of these trends have significant values.

- Cooling trend is observed mostly in minimum temperature of some stations for different seasons.

- Warming is more rapid after 1960 A.D.

- Warming rate over western Himalaya is higher compare to any other part of India and globe.

- The analysis indicates different patterns of rainfall variability within a short distance and do not indicate any significant trend during the 20^{th} century except few stations.

- In a broader sense, long-term decreasing tendency of precipitation particularly in monsoon season is noticeable in Himachal and Uttarakand where as slight increasing trend in Kashmir and further northwest region.

Summary

- Dendroclimatic reconstructions from various Himalayan regions provide some clues and indications of long-term climate changes since last several centuries.
- Most of them give information on summer temperature conditions of the region. Few epochs of medieval warming, LIA cooling are the common pattern observed in these reconstructions.
- Significant warming trend since last few decades is also observed in most of the reconstructions.
- Few precipitation reconstructions indicate wetter conditions in recent years since last millennium particularly over the northwest Himalaya including Kashmir and Karakoram ranges.
- It is also seen that high altitude near glaciers tree-ring records would be the potential source of information on long-term temperature variability and glacier fluctuations.

Thank you