Recent warming over western Himalaya, India observed from tree-ring estimates since A.D. 1603

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Abstract

High altitude near glacier tree-ring chronologies of *Cedrus deodara* (Roxb.) G. Don from Western Himalaya show unprecedented surge in growth since 1930s. They do not show any other such significant episode of higher growth prior to 1930s. This may be explained as an effect of winter warmth. The anomalous behavior of tree growth is strongly associated with the warming trend during the 20th century observed from instrumental records of temperature. Tree-ring estimates of winter (November-February) maximum temperature also indicates unprecedented warming during recent decades since A. D. 1603. Similar anomalous increase in temperature also noticed in Northern Hemispheric temperature derived from proxy data network for the past millennium.

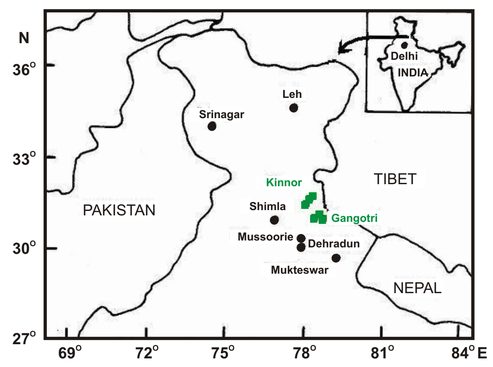
Tree-Ring Data

Two tree-ring width index chronologies of Himalayan Cedar [*Cedrus deodara* (Roxb.) G. Don] from high- altitude, near-glacier sites of Western Himalaya

Gangotri Chronology : 45 tree-ring index series

Kinnor Chronology : 40 tree-ring index series

Minimum individual series length : 300 years.



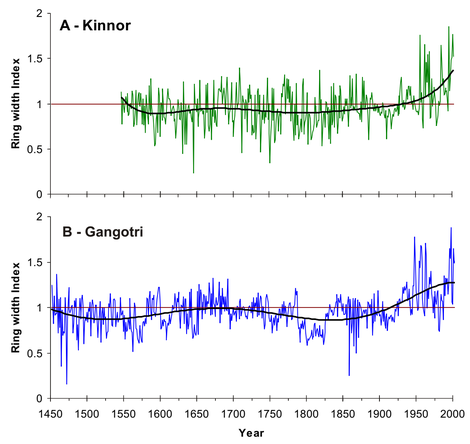
Location Map of Meteorological stations and Tree-ring sampling sites.
● Met. Stations; ■ Tree-ring Sites.

Climate Data

Monthly maximum, minimum and mean surface air temperatures anomalies of Western Himalaya based on six stations for the period 1901-2003.

Monthly rainfall anomalies of Western Himalaya based on 15 stations for the period 1901-2003.

(A & B) Tree-ring sampling site near Sangla glacier, Kinnor (Alt. 3200M amsl); (C & D) Tree-ring sampling site near Gangotri (Alt. 3250M amsl), Western Himalaya.

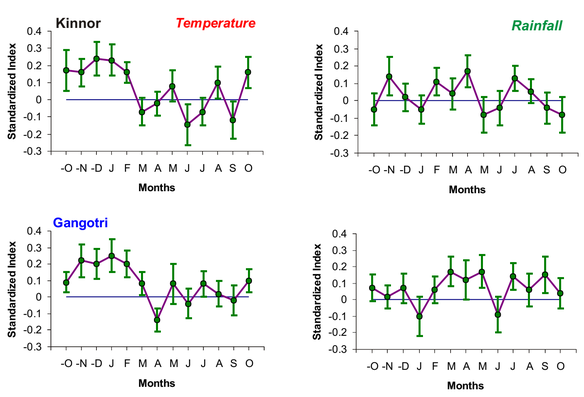


Tree-ring width index chronologies from (A) Kinoor, (B) Gangotri, Western Himalaya, India. Smooth lines are low-frequency variations.

Linear trends (°C/10 yrs) in temperatures over Western Himalaya

		DJF			MAM			JJAS			ON			ANNUAL		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Station	Period															
LEH	1901 - 1990	.15	-.03	.06	.07	.22*	.14*	.34*	.37*	.36*	.06	-.02	.02	.18*	.18*	.18*
	1961 - 1990	1.09*	.06	.58	.79*	.74	.76*	.75*	1.9*	.32*	.73*	.43	.57	.85*	1.04*	.94*
SRN	1901 - 2003	.13	.08*	.11*	.09	.04	.06	.02	.01	.01	.25	.12*	.18*	.10	.05*	.08*
	1961 - 2003	.86*	.35*	.61*	.43	.18	.30	.07	.19	.13	.15*	.10	.83*	.60*	.22	.41*
SHM	1901 - 2003	.35*	.08*	.21*	.27*	.06	.16*	.25*	0.0	.13*	.58*	.05	.31*	.33*	.04	.19*
	1961 - 2003	.73*	.57*	.65*	.55*	.39*	.47*	.54*	.42	.48*	1.9*	.43*	.18*	.80*	.45*	.62*
DDN	1901 - 1990	.14*	-.17*	-.01	-.03	-.21*	-.12*	0.0	-.20*	-.10*	.08	-.13*	-.03	.03	-.19*	-.08*
	1961 - 1990	.49	.03	.26	-.78*	-.45*	-.62*	-.10	-.23	-.16	.13	-.18	-.03	.16	-.24	-.20
MUS	1901 - 1990	.26*	.02	.14*	.08	-.01	.04	.02	-.04	-.01	.19*	.02	.11	.12*	-.01	.05*
	1961 - 1999	.21	.20	.20	-.41	-.31	-.36	.07	-.04	.01	.02	.19	.10	-.09	-.03	-.06
MKT	1901 - 2003	.31*	-.02	.14*	.15*	-.09	.03	.10*	-.10	0.0	.23*	-.05	.09*	.18*	-.07	.06*
	1961 - 2003	.55*	.03	.29*	.13	-.22	-.05	.10	-.13	-.02	.38	.09	.23	.22*	-.08	.07
W. H.	1901 - 2003	.12*	.01	.08*	.07*	.01	.04*	.10*	-.02	.06*	.10*	.01	.07*	.10*	0.0	.06*
	1961 - 2003	.29*	.21*	.30*	.18	.10	.15	.19*	.23	.25*	.29*	.22	.33*	.23*	.20	.26*

LEH : Leh; SRN : Srinagar; SHM : Shimla; DDN : Dehradun; MUS : Mussoorie; MKT : Mukteswar; W. H. : Western Himalaya
* = $p < 0.01$; + = $p < 0.05$

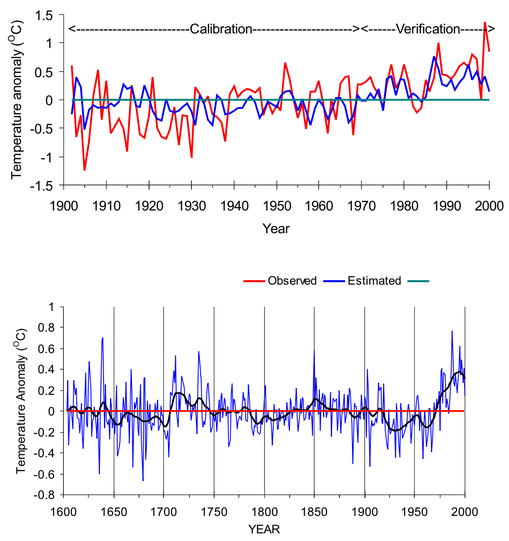


Response functions of tree-ring chronologies from Kinnor and Gangotri sites of Western Himalaya using monthly temperature and rainfall anomalies of Western Himalaya. Error bars are 95% confidence intervals.

Calibration and verifcation tests of Western Himalayan winter temperature estimated from Kinnor and Gangotri tree-ring chronologies for different periods.

CALIBRATION					VERIFICATION				
Variables	Calibration Period	F	Multiple r	Variance explained (%)	Verification Period	Corr. Coeff.	Reduction of Error (RE)	Product Mean 't'	Sign test
Dec-Feb Temp.	1901-1965 (65 years)	5.2	.52***	27	1966-2002 (37 years)	.45**	.22*	2.14*	22/37*
Dec-Feb Temp.	1938-2002 (65 years)	2.2	.44***	19	1901-1937 (37 years)	.37*	.13	1.03	20/37
Oct-Feb Temp.	1901-1965 (65 years)	5.9	.62***	38	1966-2002 (37 years)	.52***	.32*	3.05*	26/37*
Oct-Feb Temp.	1938-2002 (65 years)	3.4	.53***	28	1901-1937 (37 years)	.40**	.16	1.49	20/37

** Significant at 5 % level; ** Significant at 1 % level; *** Significant at .1 % level;*



Reconstruction of Winter (October-February) maximum temperature from tree-rings over the Western Himalaya. (A) Observed and estimated values during 1901-2002. (B) Reconstruction since A.D. 1603. Smooth line is 40 years cubic spline fit.

Response Function Analysis

Kinnor and Gangotri tree-ring index chronologies as predictands.

Monthly anomalies of maximum temperature and rainfall over western Himalaya as predictors.

Analysis Period : 1901-2002.

The characteristic feature : Similar patterns of positive response of maximum temperature during winter months to tree growth in both the chronologies.

Response to the winter temperature may be due to the winter warmth. The warm weather in winter may result in thawing of tissues that leads to affect the subsequent growth which gives relationship between winter temperature and tree growth

Reconstruction of winter temperature since A.D. 1603

Two winter temperature parameters namely December-February (DJF) and October-February (ONDJF) mean maximum temperature anomalies have been estimated for two different calibration periods using orthogonalized stepwise multiple regression procedure with Kinnor and Gangotri tree-ring index chronologies as predictors.

Reconstruction of October-February (ONDJF) mean maximum temperature based on 1901-65 calibration and corresponding verification is the best among the all.

Reconstruction of winter mean maximum temperature (ONDJF) over Western Himalaya since A.D.1603 during which acceptable replication of the samples are available (Agreement with Population Chronology, APC > .85).

Summary

- Tree-ring estimates of winter (November-February) maximum temperature indicates unprecedented warming during recent decades since A. D. 1603. This is corroborated by increasing trend in the observed temperature records of the 20th century as well as few other tree-ring based temperature reconstructions over different parts of the Himalaya. Similar anomalous increase in temperature also noticed in Northern Hemispheric temperature derived from proxy data network for the past millennium.
- This probably indicates that the Western Himalaya follows the pattern of global warming in the 20th century.