PALEOCLIMATOLOGY

Forecasters Training Course Batch No. 192

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23.02.2022

Natural Events Affecting Climate

Earth's climate is complex

- **There are a number of factors that have affected our climate in the past and continue to do so today**
- **These are called Climate Forcing**
- **These include:**
  - **Milanokovitch Cycles**
  - **Sun Spots and Solar Flares**
  - **Plate Tectonics**
  - **Major Volcanic Eruptions**
  - **El Nino and La Nina**
  - **Forest Fires**

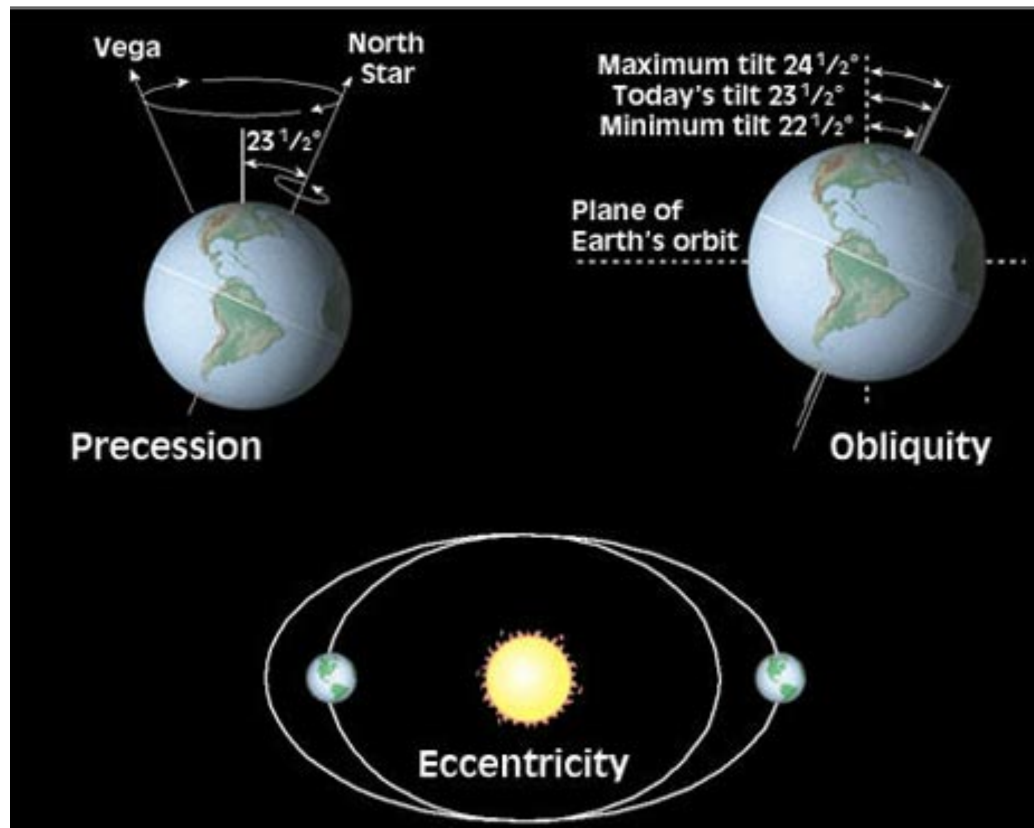
Climate Forcing

Forcing	Response	Lag
Mom tells me, "Clean your room!"	I clean my room.	I do it 3 days later.

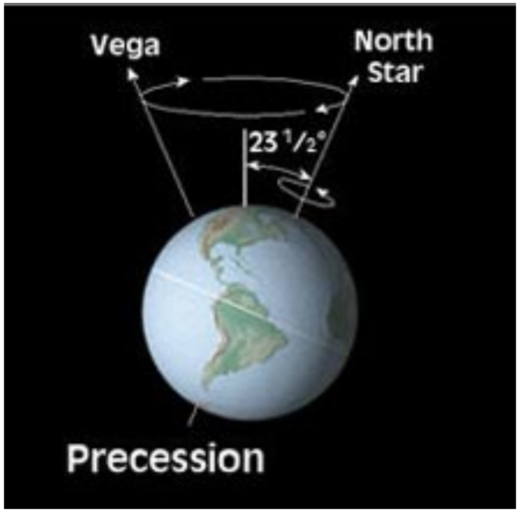
Forcing: A *forcing* is any event or thing that *causes* or leads to change.
Response: The *response* is the result or change from the forcing.
Lag: The *lag* is how long after the forcing that the response starts to occur.

Milankovitch Cycles

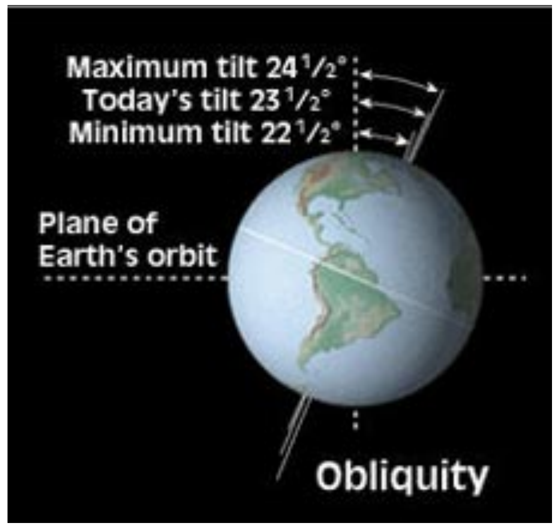
- **Named after a Serbain mathematician, Milutin Milankovitch**
- **EXTREMEMLY long term effects that scientists think may be the cause of the ice ages.**
- **These are movements of the Earth that affect the amount of solar radiation that it gets.**



Milankovitch Cycles

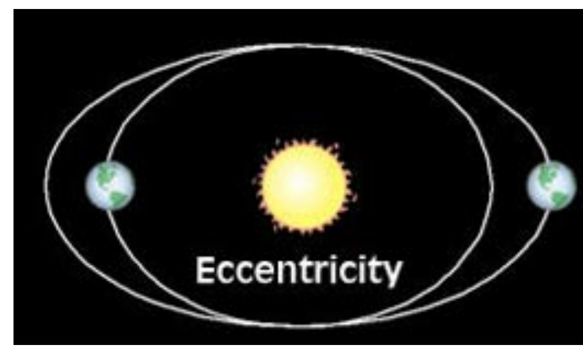


Precession



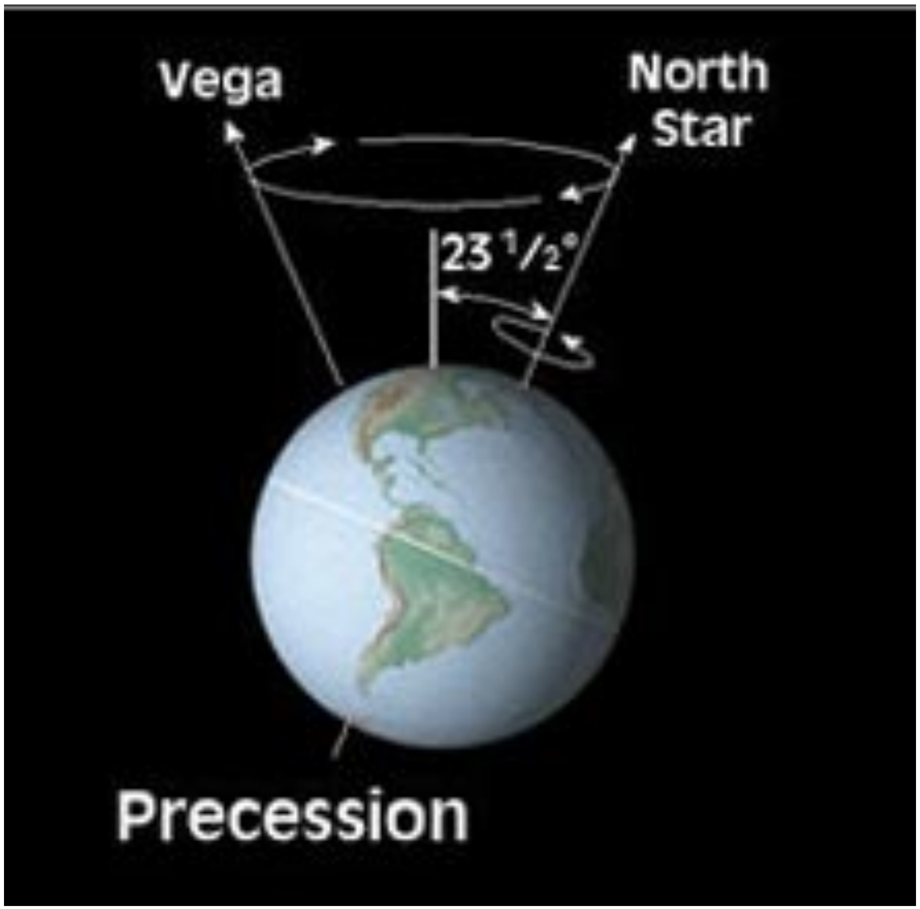
Obliquity

Earth's wobble, tilt, and orbit



Eccentricity

Milankovitch Cycles



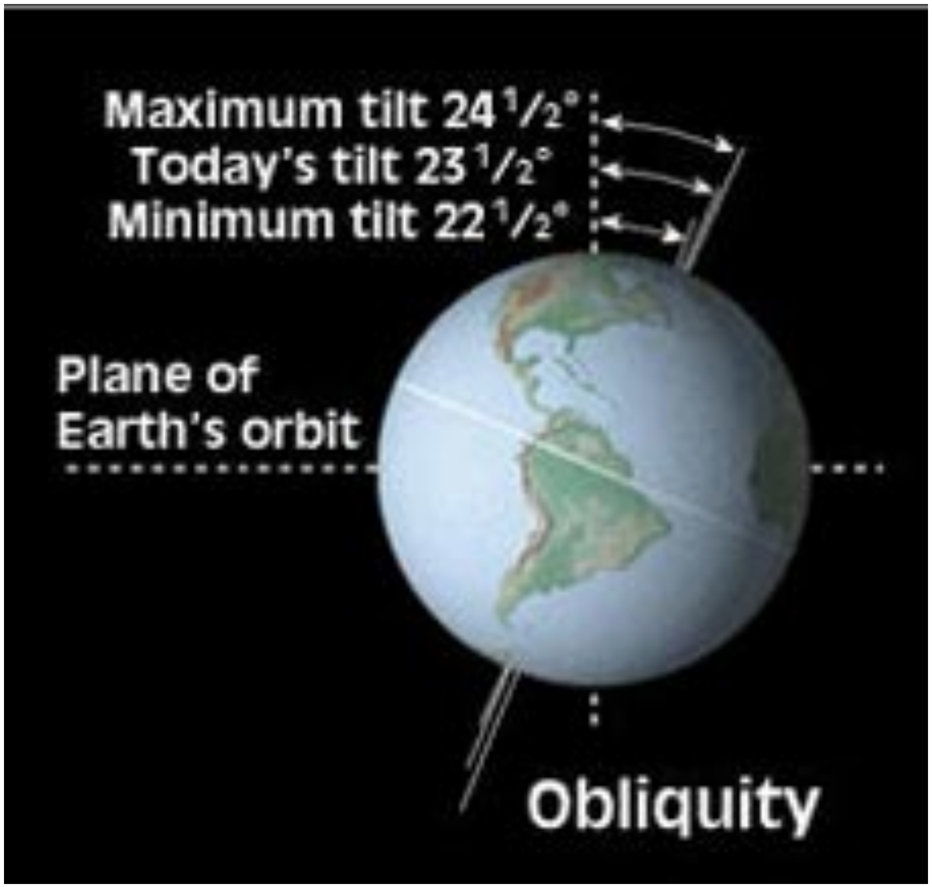
Precession

Direction of the Earth's axis changes over time

The Earth ***wobbles*** like a top on its axis

26,000 year cycle

Milankovitch Cycles



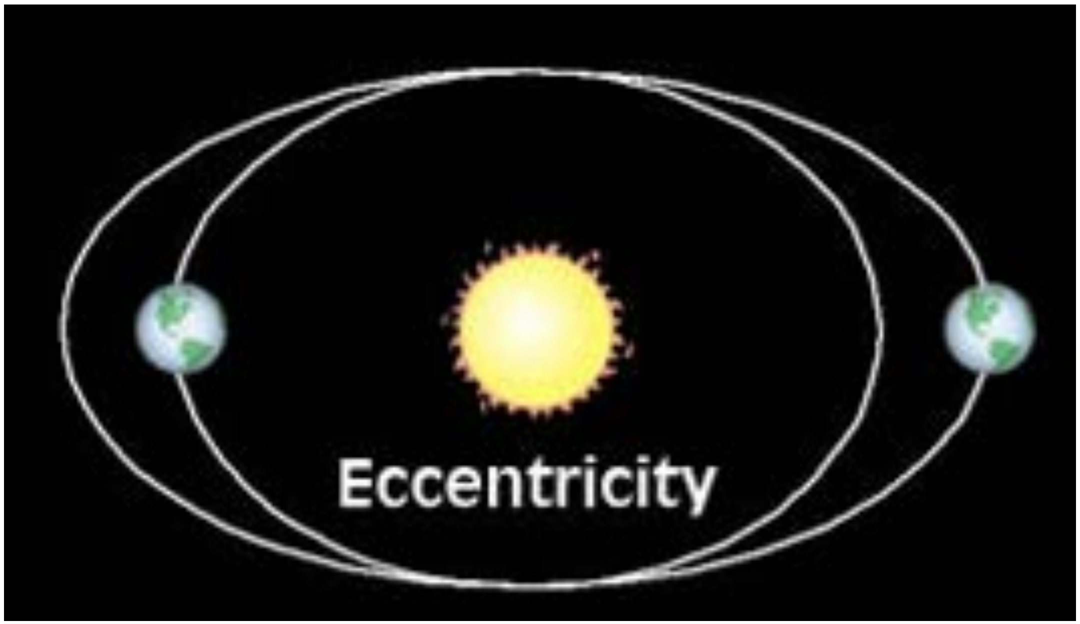
<u>Obliquity</u>

The tilt angle of the Earth's axis changes over time

The greater the tilt the greater the differences in the seasons.

40,000 year cycle

Milankovitch Cycles



Eccentricity

Varying shape of Earth's orbit, e.g. how elliptical it is

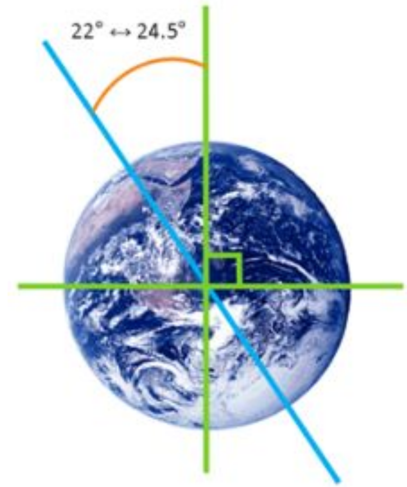
100,000 year long cycle

Question #2

This term refers to the wobble of the Earth on its axis:

A. Perihelion
B. Eccentricity
C. Obliquity
D. Aphelion
E. Precession

Question #3



How would an **increase** in the tilt of the Earth influence the seasons in Canada?

A. Warmer summers and warmer winters

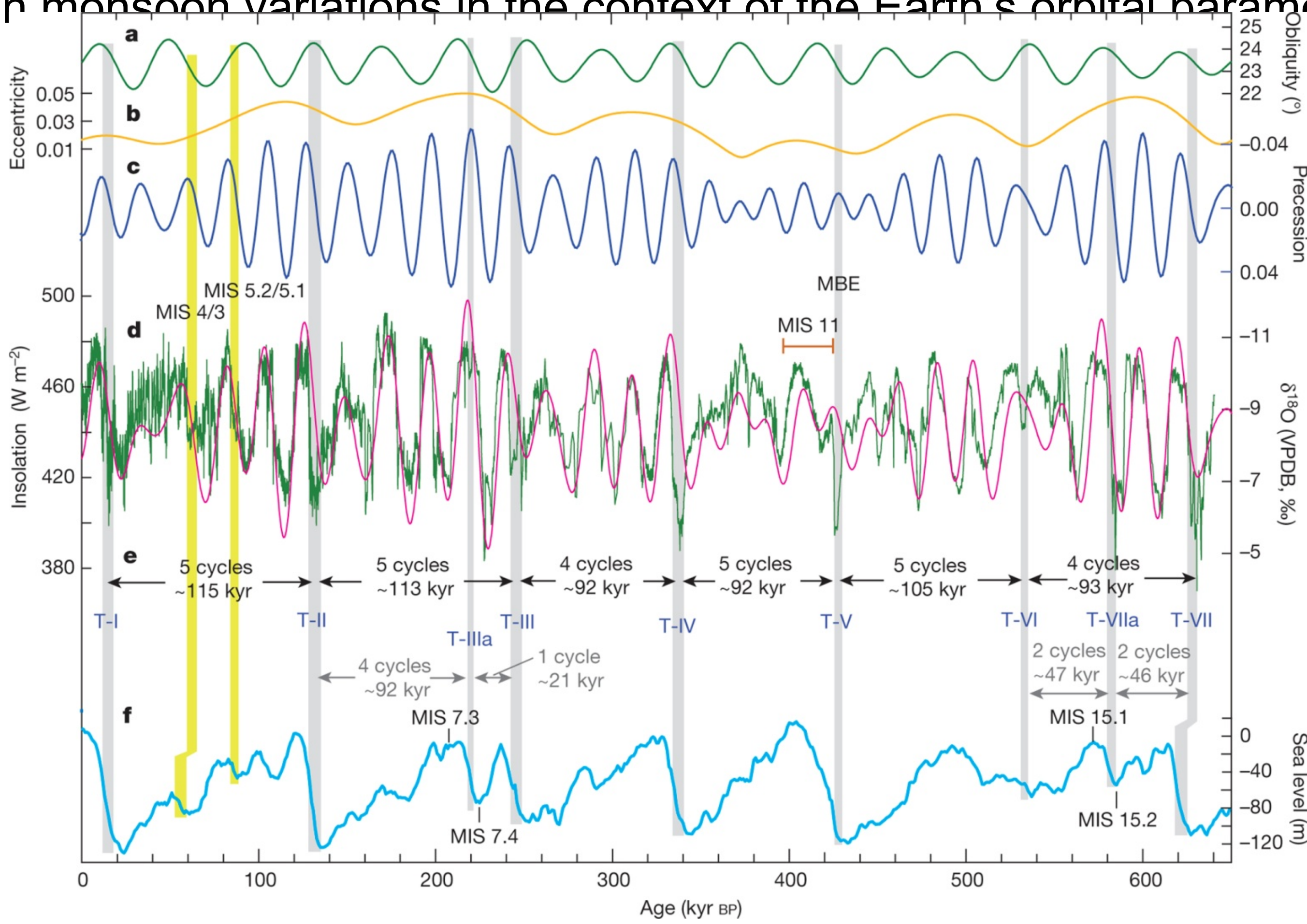
B. Warmer summers and colder winters

C. Colder summers and warmer winters

D. Colder summers and colder winters

E. A change in the tilt would NOT affect the seasons.

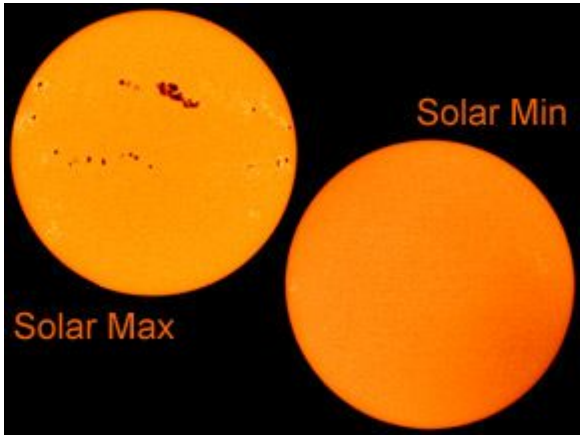
Asian monsoon variations in the context of the Earth's orbital parameters



H Cheng *et al.* *Nature* **534,** 640–646 (2016) doi:10.1038/nature18591

Solar Cycles

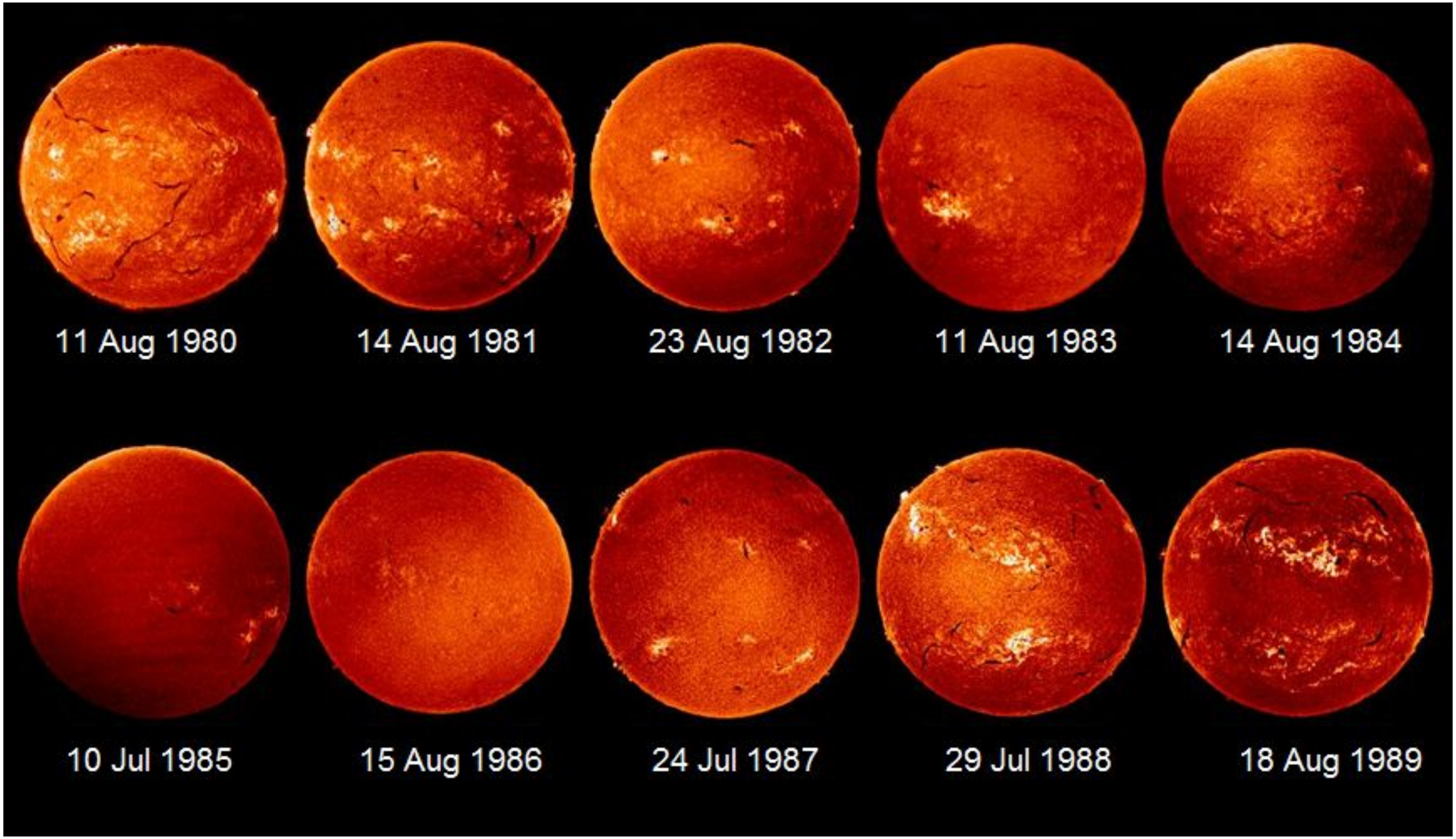
Sunspots are storms on the surface of the sun and are associated with extremely strong magnetic activity, solar flares hot gaseous emissions



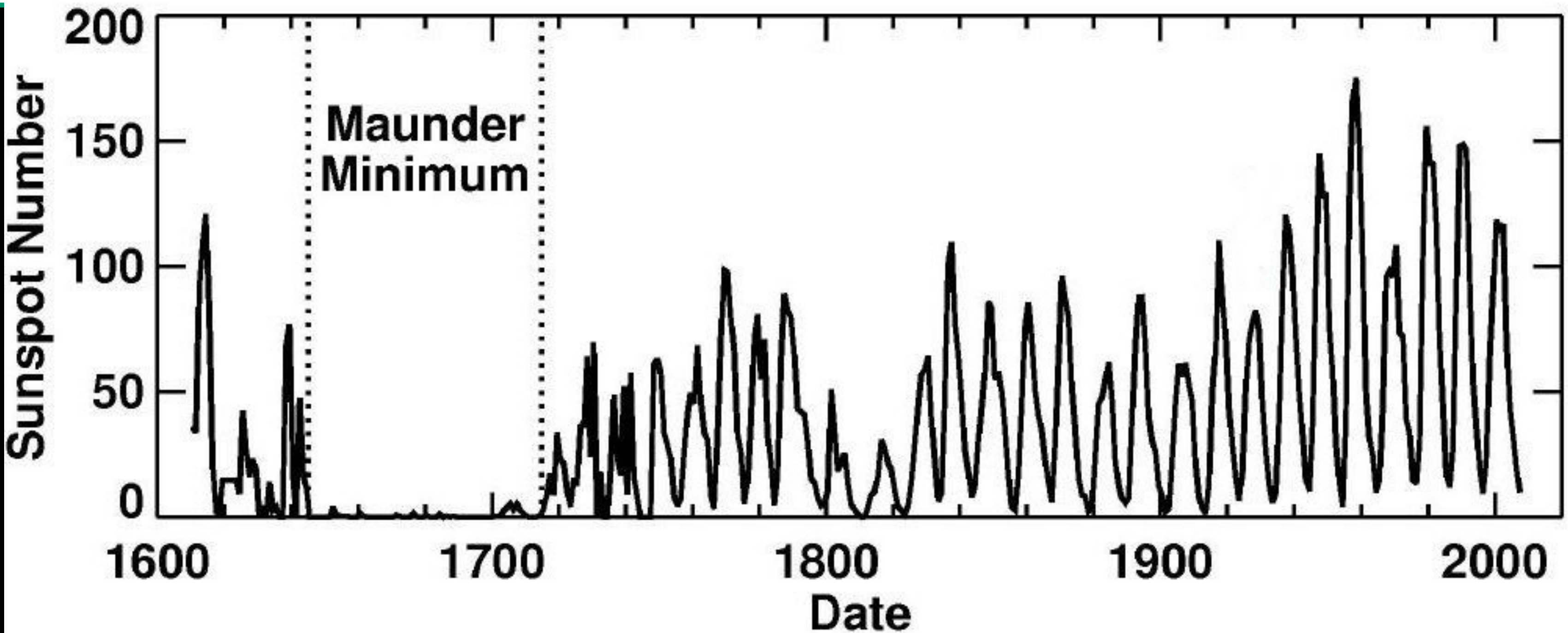
These follow an 11 year cycle.

Scientific research estimates that normal fluctuations due to Solar Cycles increase or decrease solar radiation reaching Earth by only 0.1% - 0.2%.

Images of the Sun's changing surface activity



400 Years of Sunspot Activity



Source: Nasa Science News
http://science.nasa.gov/science-news/science-at-nasa/2009/29may_noaaprediction/

Question #4

A high number of Sun Spots, which indicate a large amount of storm activity on the surface of the sun

A. result in a 2^{o}C to 5^{o}C increase in Earth's temperature.
B. result in a 2^{o}C to 5^{o}C decrease in Earth's temperature.
C. will have no effect on the Earth's temperature.
D. increase the solar radiation reaching the Earth by 10%
E. Increase the solar radiation reaching the Earth by only a fraction of a %.

Question #5

The length of the Solar Cycles is

A. 11 years
B. 350 years
C. 500 years
D. 1 000 years
E. 10 000 years.

Plate Tectonics

Plate Tectonics and associated Continental drift

- **Have been exerting their effect on the Earth’s geography over billions of years**
- **Have shaped the continents as we know them**
- **The impact on climate (very long term, and in the past) was:**
  - **by changing <u>land mass</u> and <u>ice caps</u> (size & location) <u>and</u>**
  - **changing <u>ocean circulation patterns</u> which transport heat around the Earth <u>and</u> in turn**
  - **influences <u>atmospheric circulation processes</u>.**

Volcanic Eruptions

Volcanic eruptions of ash and gases into the troposphere and above cause SHORT TERM cooling (few years).

The gases released are mainly water (H_2O), carbon dioxide (CO_2) and sulfur dioxide (SO_2). The 1st 2 do not change ambient levels by much. But the SO_2 reacts with H_2O to form sulfates. Sulfates increase the brightness (albedo) of clouds, reducing the solar radiation reaching Earth.

The large volumes of ash also block some incoming solar radiation but the effect is less significant and more short lived.

Volcanic Eruptions

Do Volcanic eruptions cause long term climate change?

Apparently **not.**

There is evidence of slight warming at some times, and slight cooling at other times. In these cases any temperature changes are minimal and short lived.

Interesting point:

During the time before and at the beginning of the Little Ice Age, there was an increased incidence of volcanic activity – enhancing the effect of the Sun Spot minimum.

Question #6

Continental Drift as a result of Plate Tectonics

A. is a major contribution to today's climate change.
B. affected Earth's climate millions of years ago.
C. impacted Earth's climate by causing the ocean and atmospheric currents to change.
D. Both A and C.
E. Both B and C.

Question #7

Volcanic Eruptions

A. cause climate warming over a long term basis.
B. cause temporary (few years) cooling of the Earth.
C. only cause additional climate warming *after* the temperature recovers from the cooling period.
D. cause long term (decades) cooling of the Earth.
E. had nothing to do with the Little Ice Age.

El Niño/La Niña

El Niño is a large scale change in oceanic and atmospheric circulation in the eastern equatorial Pacific and involves rapid, large scale warming of the sea-surface.

Peruvian fishermen have noticed this because the warming is linked to a stop in the upwelling of deep nutrient-rich cold water just off their coast. During an El Niño event, this lack of nutrients reduces the productivity of the ocean and fish populations decline dramatically.

La Niña is the opposite, a rapid cooling in this area.

El Niño/La Niña

Impacts:

- Tradewinds are weaker than average
- Causing pools of warm water to move eastward across the ocean towards South America
  - The cold upwelling water is reduced, the water warms (and levels rise) causing the fish to move away
  - Warm waters produce lower air pressures, which increase convection, and increase rainfall – which can cause flooding.
- In tropical western Pacific (e.g. New Zealand) there is a slight decrease in ocean levels, lower convection and drought conditions

Forest Fires

Forest fires produce a lot of smoke – made up of particulates and gases.

Based on what you learned about volcanic activity, what impact could large forest fires have on climate?

-will this impact be local? Global?

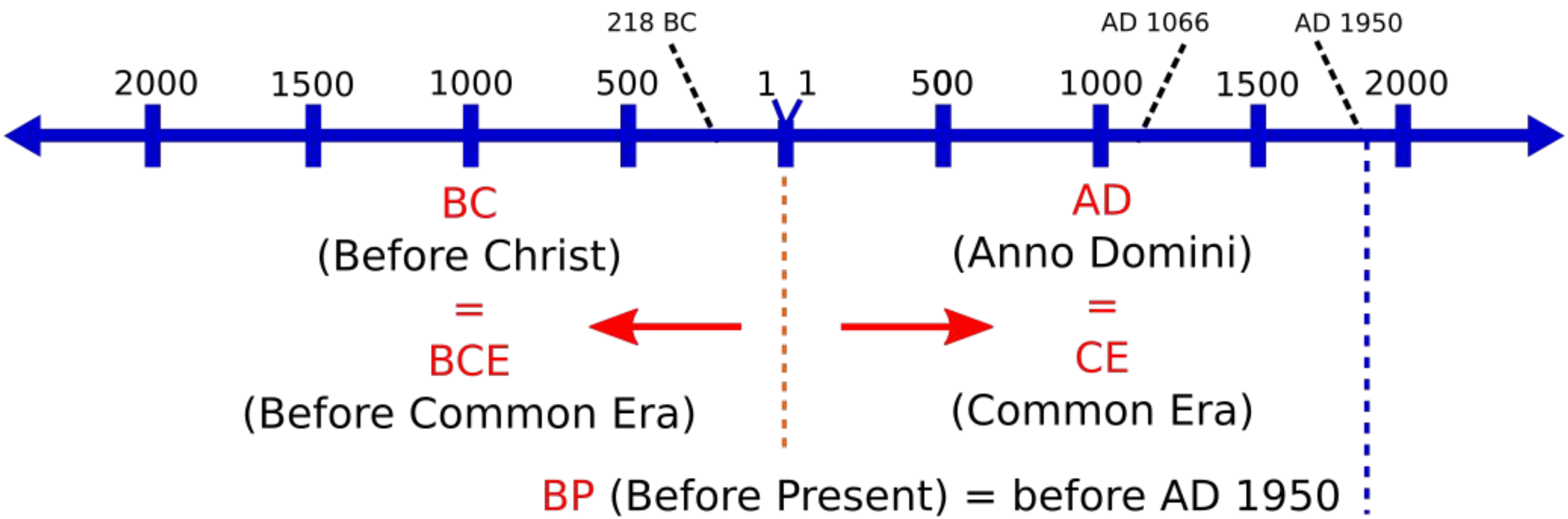
- **Forest fires can cause local temporary cooling - but to a much smaller degree than Volcanic activity.**

- **Large volcanoes send ash and more significantly gases (including sulfur compounds) very high into the atmosphere where they can be influenced by high altitude winds and circulate on a global scale.**

- **Forest fires, in contrast, produce little sulfur emissions and the smoke typically remains at low altitudes. The ash usually remains relatively local and is “washed out” quickly.**

- **Note also that forest fires increase when drought conditions and warmer temperatures occur. So, unlike volcanoes the actual frequency and severity of forest fires responds to climate change!**

BC - BCE and AD - CE Terms

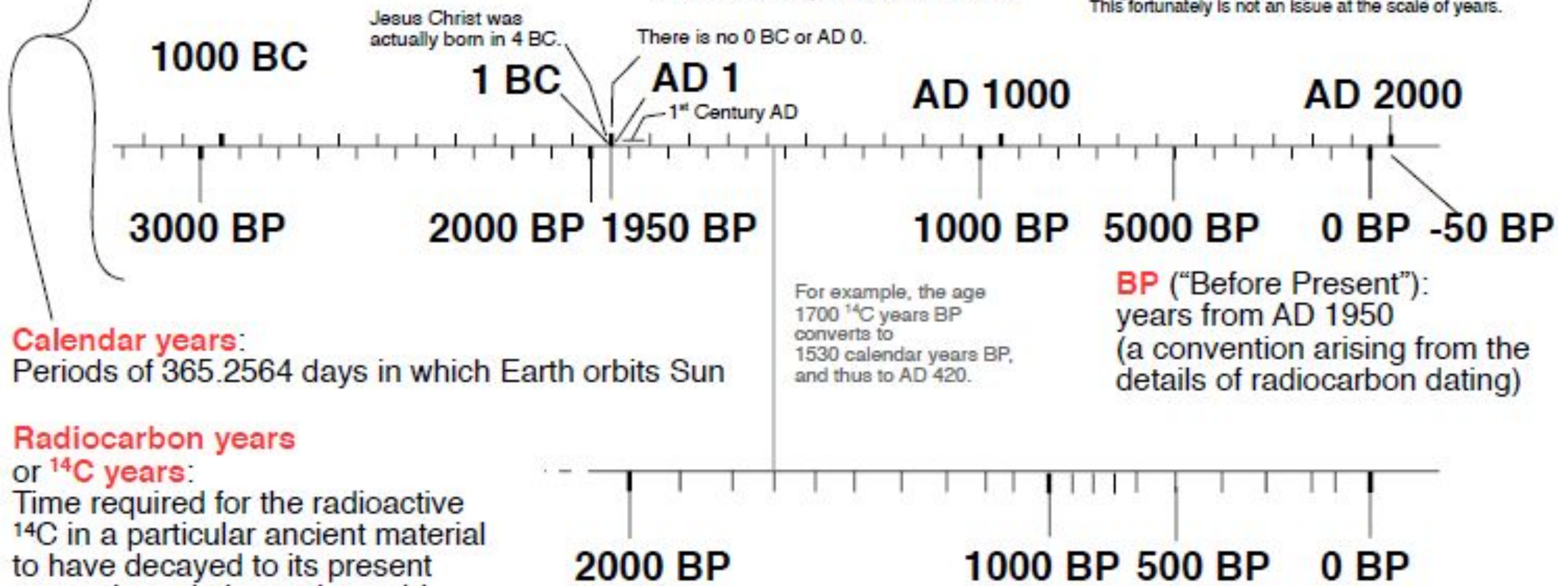


AD, CE, BC, BP, calendar years, radiocarbon years, and all that

BC ("Before Christ"): years before the nominal birth of Jesus Christ, also designated **BCE** ("Before Common Era")

AD (Anno Domini, "the year of the lord"): years since the nominal birth of Jesus Christ, also designated **CE** ("Common Era")

The Julian Calendar used in Europe from 45 BC until the Second Millennium AD assumed a year of 365.25000 days (rather than the actual 365.256363 days). It was replaced by the Gregorian Calendar, which was first adopted in AD 1582 in Roman Catholic countries and later in other countries. To avoid confusion of daily dates during the period of use of both calendars, dates in the Julian system are designated "Old Style" (OS) and those in the Gregorian system are designated "New Style" (NS). This fortunately is not an issue at the scale of years.



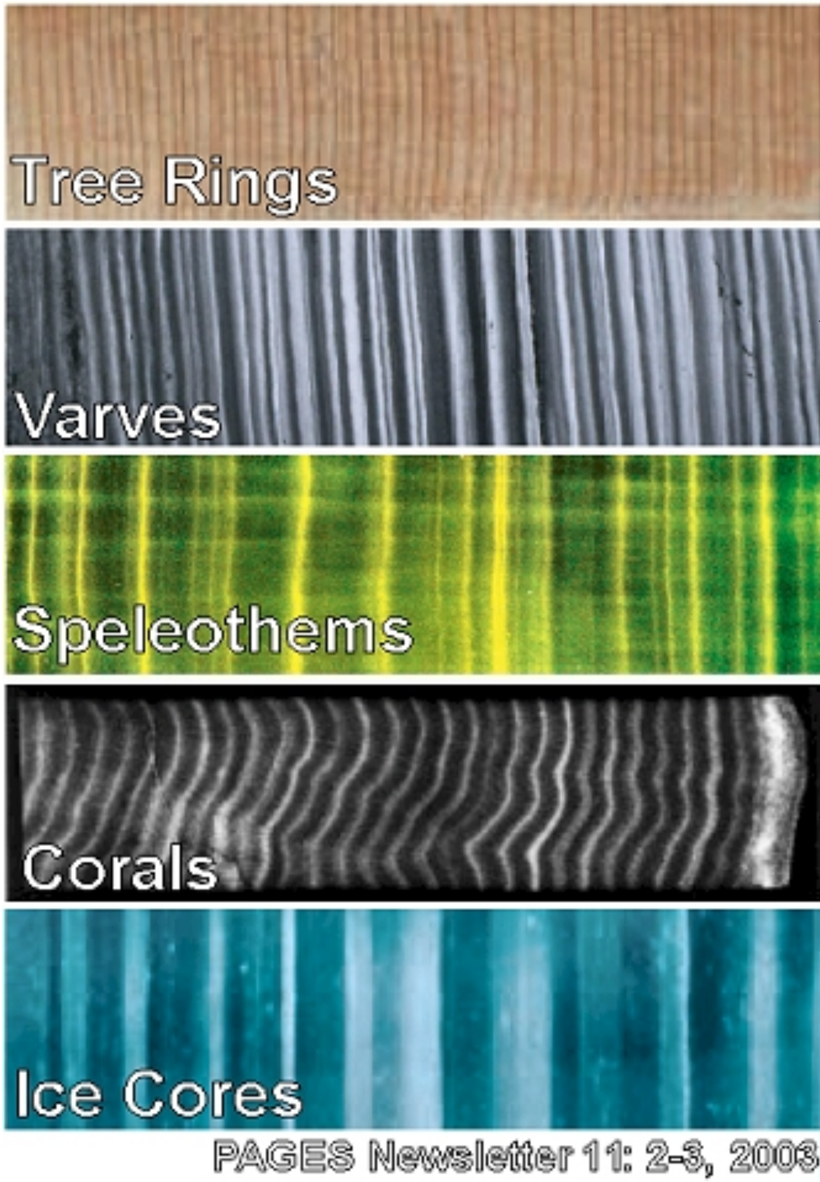
BP ("Before Present"): years from AD 1950 (a convention arising from the details of radiocarbon dating)

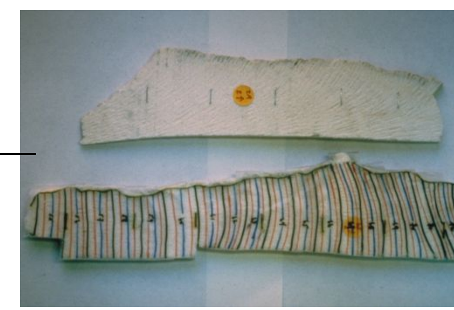
Calendar years: Periods of 365.2564 days in which Earth orbits Sun

Radiocarbon years or **^{14}C years**: Time required for the radioactive ^{14}C in a particular ancient material to have decayed to its present proportion relative to the stable ^{12}C and ^{13}C in that material, *assuming* that the ^{14}C concentration of the atmosphere when that ancient material formed was the same as that of the modern (late 1940s) atmosphere. That assumption is not valid in detail, so that measured ^{14}C ages must be converted to calendar ages. Conversion from ^{14}C years to calendar years is called "calibration" of the age. Two further *SFMG* pages address that topic.

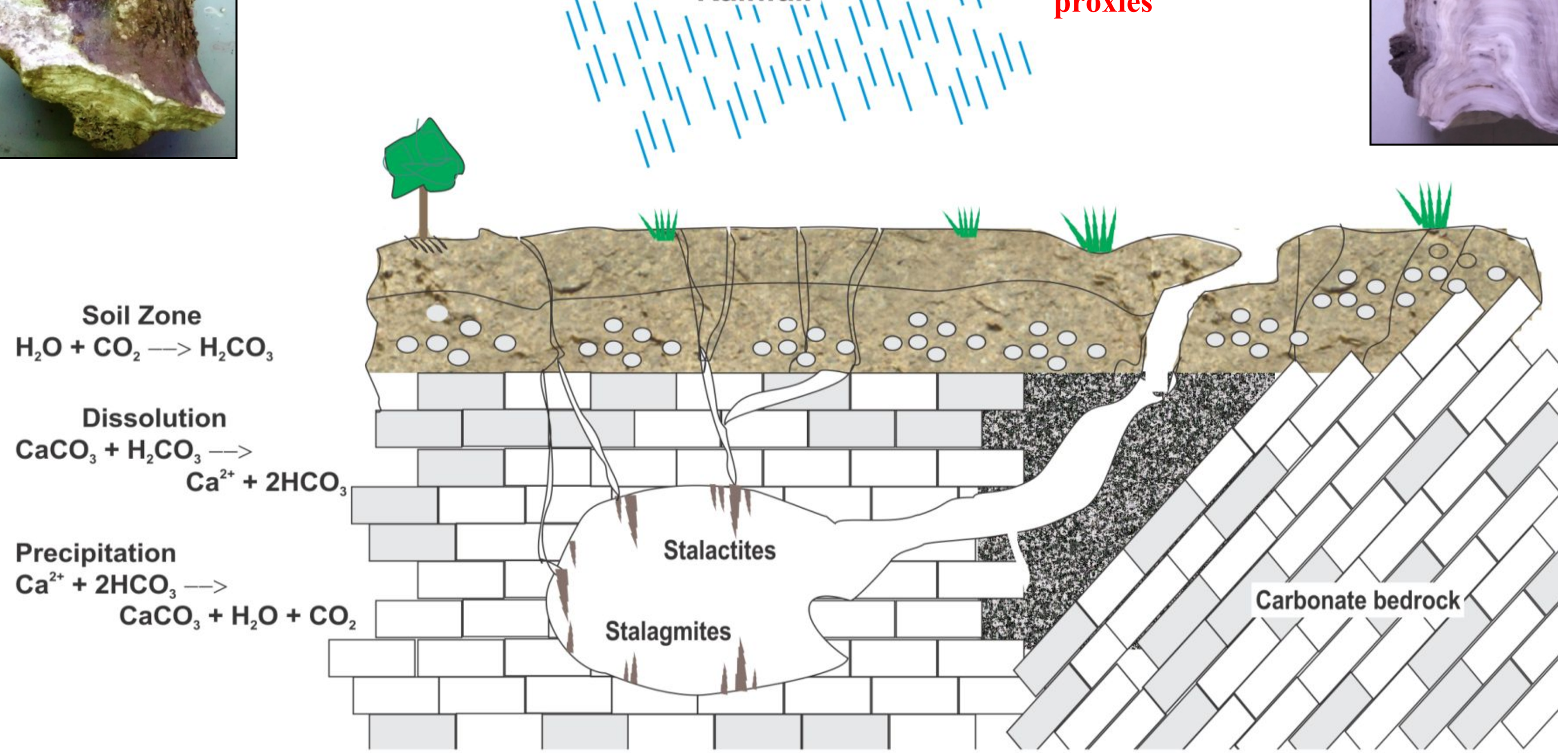
One bit of good news is that U-Th or ^{230}Th dating requires no calibration – it yields ages in calendar years. Those ages were commonly expressed relative to the time of analysis but are more recently expressed as years BP.

Proxies for palaeo/past climate studies





Speleothems



Lamination contains information about the variability of the climate in the form of proxies

Image: CorelDRAW

The seepage water also contains various ions (e.g. Mg, Ba, Sr, U) – Trace Elements

$\sim10^4$-10^5 years, highly likely that structural changes to the karsts system may occur

For paleoclimate, the past two decades have been the age of the ice core. The next two may be the age of the speleothem

Gideon Henderson (Science, 2006)

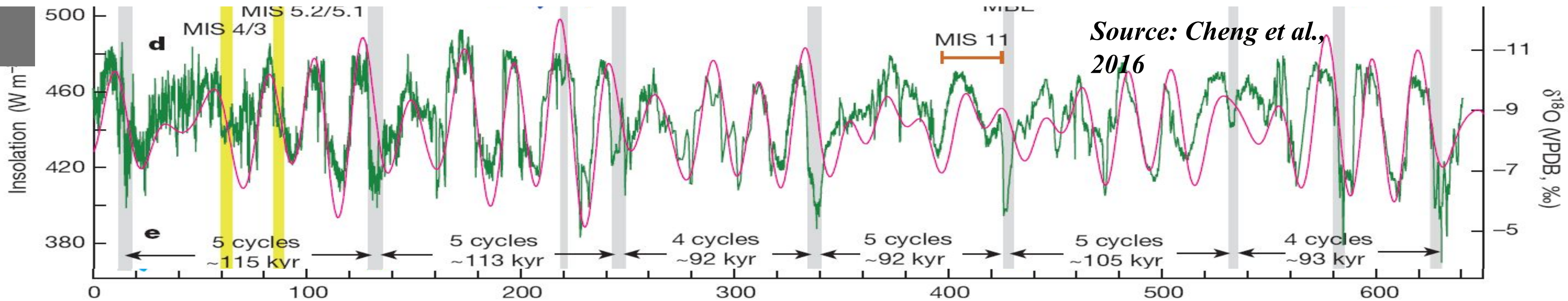
Beginning of the monsoon system and its variability

Uplift of the Himalaya and Tibetan Plateau region ~50 Myr ago → **Significant height achieved by Himalaya and Tibetan Plateau region ~10-8 Myr ago** → **Beginning of the Monsoon ~9-8 Myr ago**

Source: Zhisheng et al., 2001

last 650 kyr-

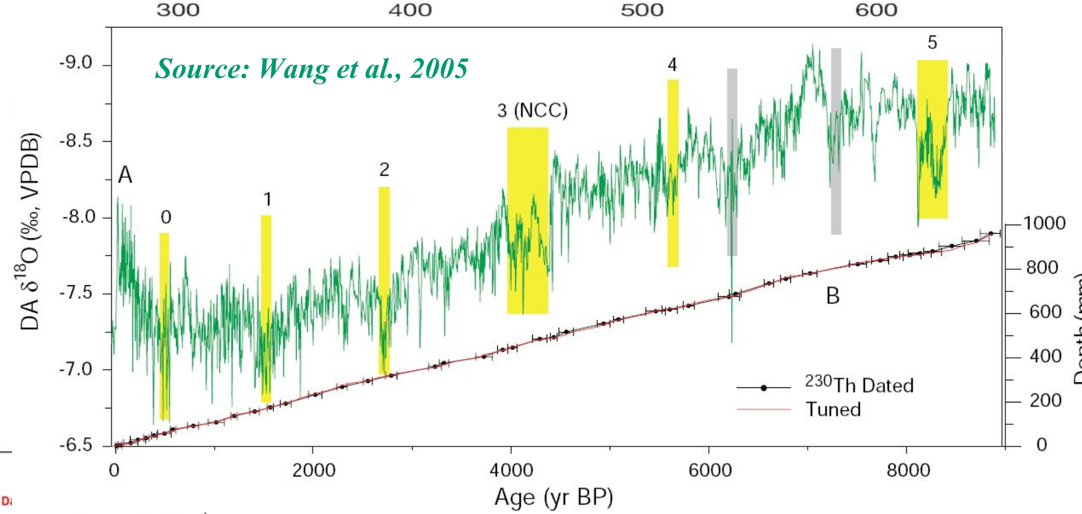
Source: Cheng et al., 2016



strong ↑ Asian monsoon ↓ weak

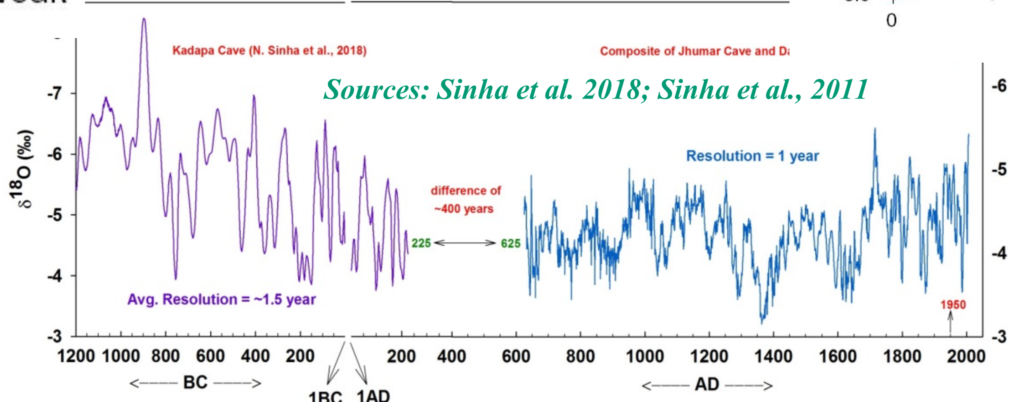
last 9kyr years-

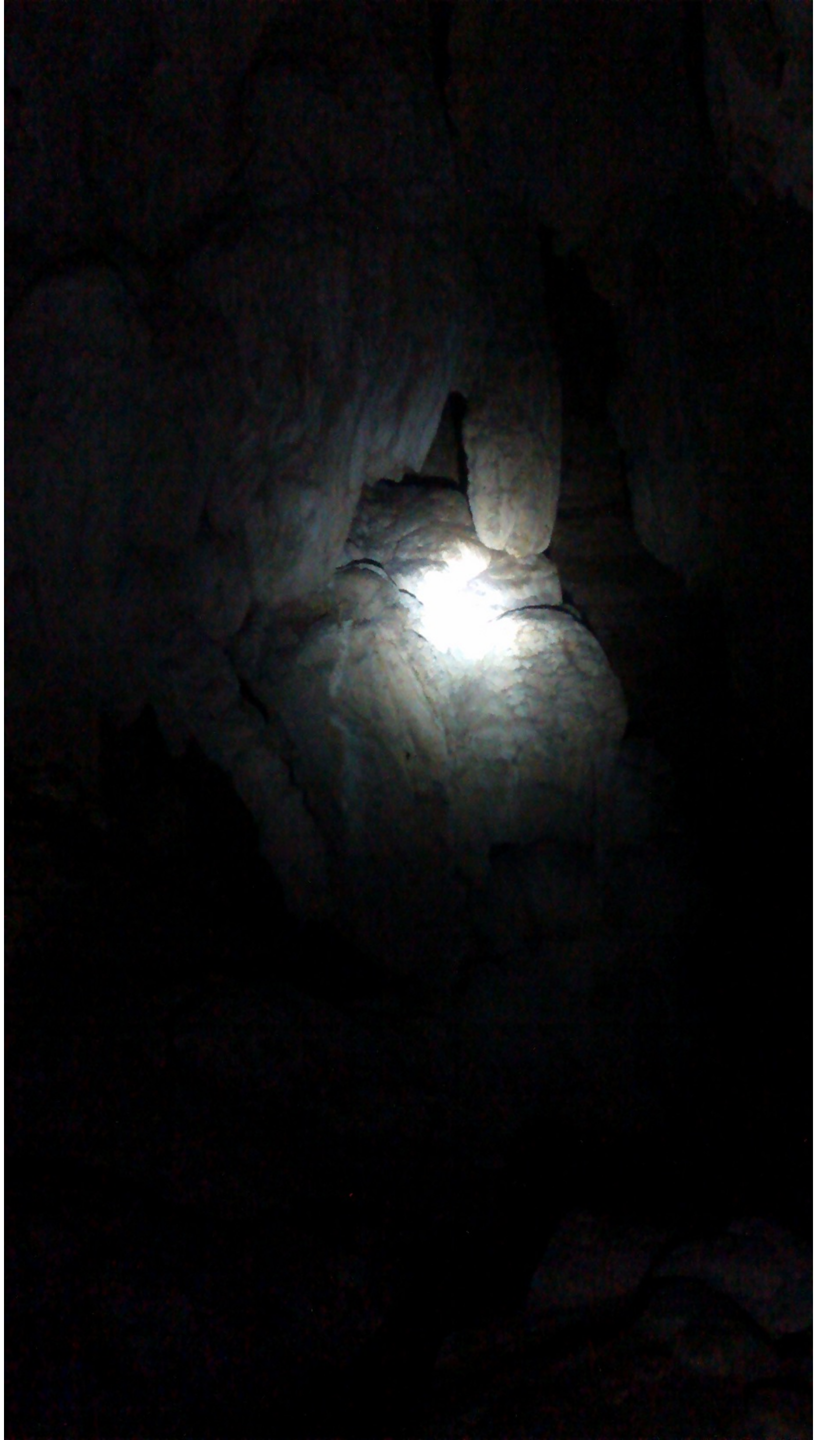
Source: Wang et al., 2005



Sources: Sinha et al. 2018; Sinha et al., 2011

last 3300 years-







A
B
C
D

Speleothem Sample Processing

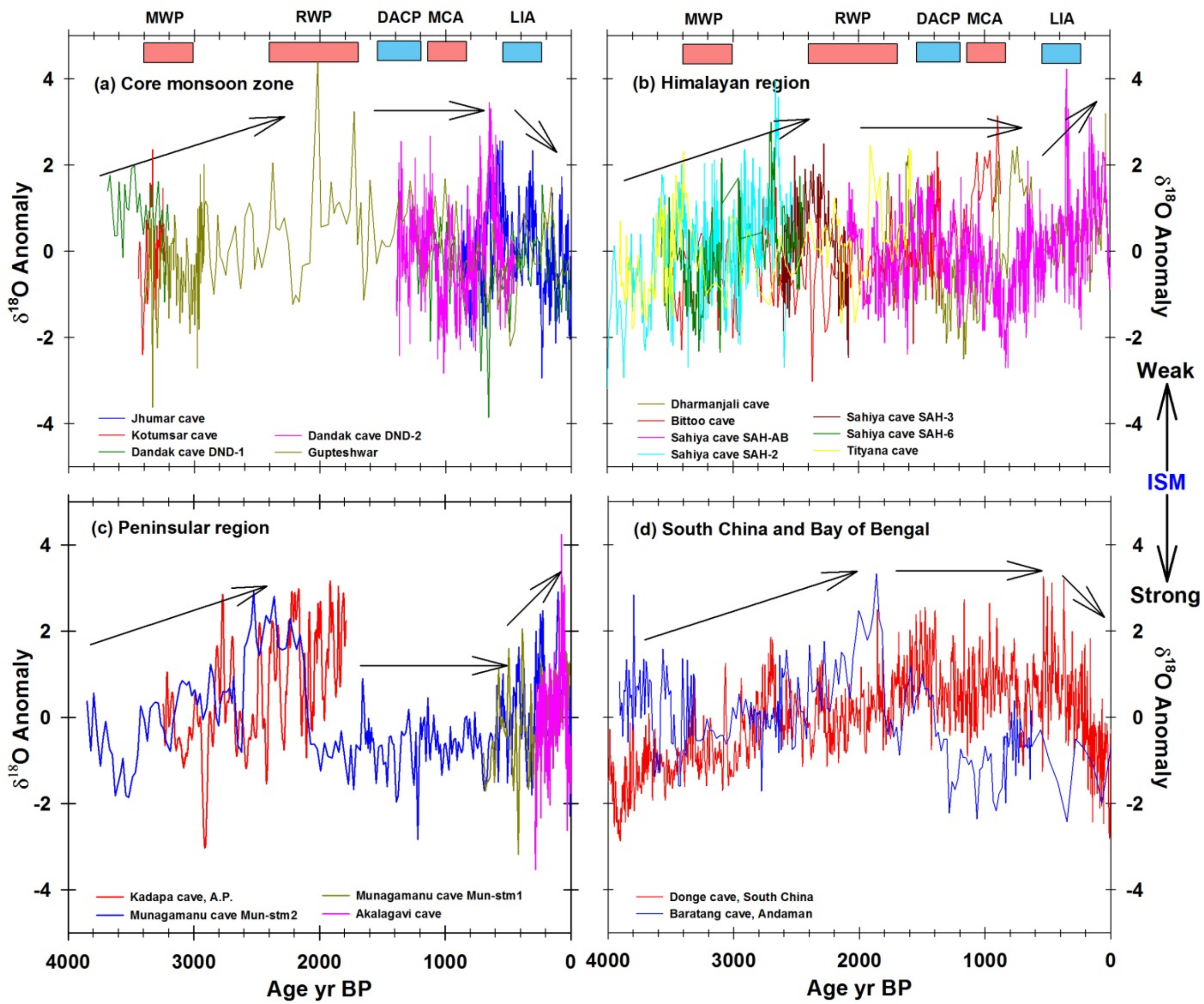
Diamond Saw Cutter

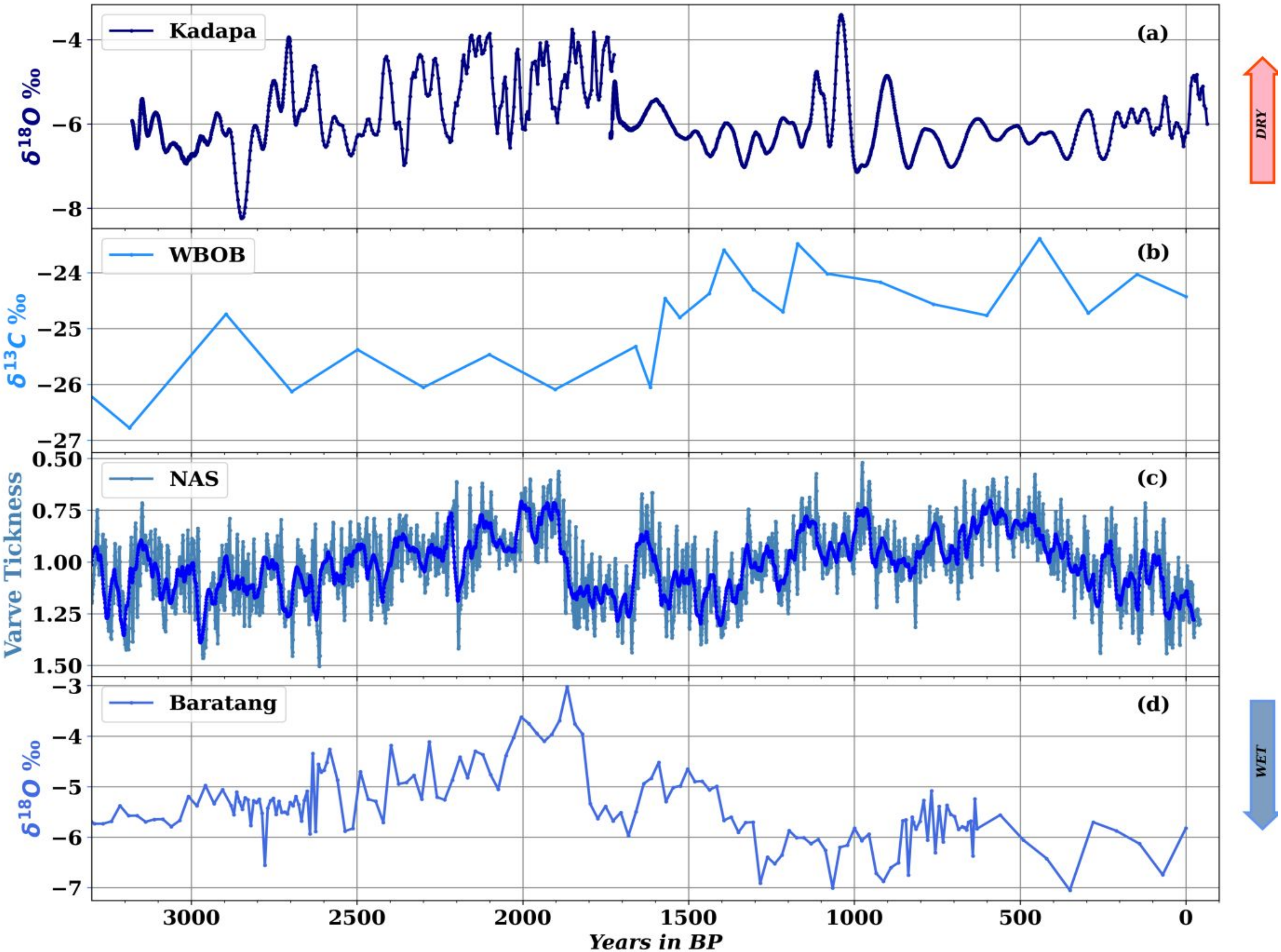
Micro-driller

$\delta^{18}O$ & $\delta^{13}C$

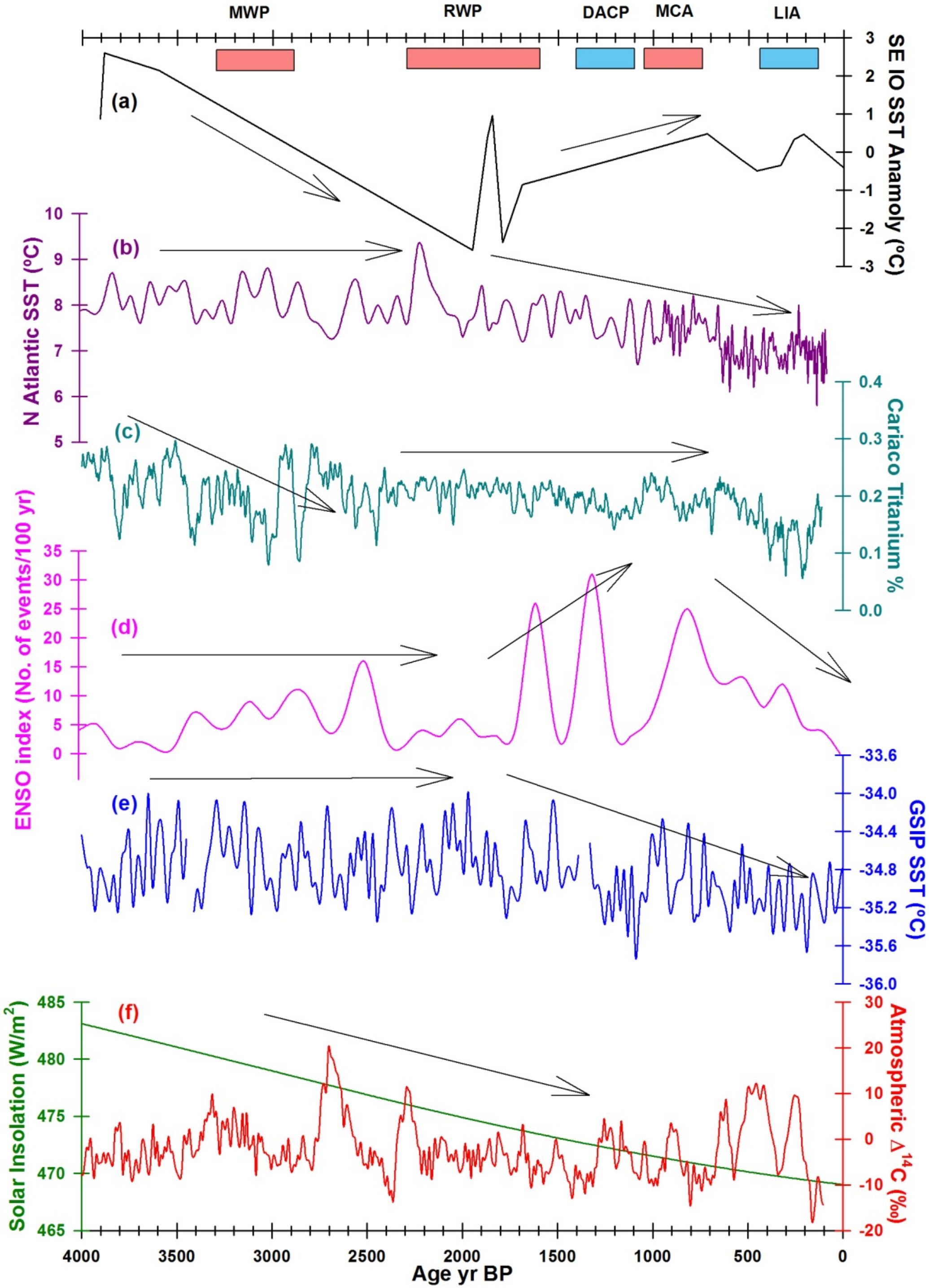
- U-Th dating
- Crystallography
- Trace element

Delta V Plus Isotope Ratio Mass Spectrometer


MWP
RWP
DACP
MCA
LIA
(a) Core monsoon zone
Jhumar cave
Kotumsar cave
Dandak cave DND-1
Dandak cave DND-2
Gupteshwar
(b) Himalayan region
Dharmanjali cave
Bittoo cave
Sahiya cave SAH-AB
Sahiya cave SAH-2
Sahiya cave SAH-3
Sahiya cave SAH-6
Tityana cave
(c) Peninsular region
Kadapa cave, A.P.
Munagamanu cave Mun-stm2
Munagamanu cave Mun-stm1
Akalagavi cave
(d) South China and Bay of Bengal
Donge cave, South China
Baratang cave, Andaman
δ18O Anomaly
Age yr BP
Weak
ISM
Strong

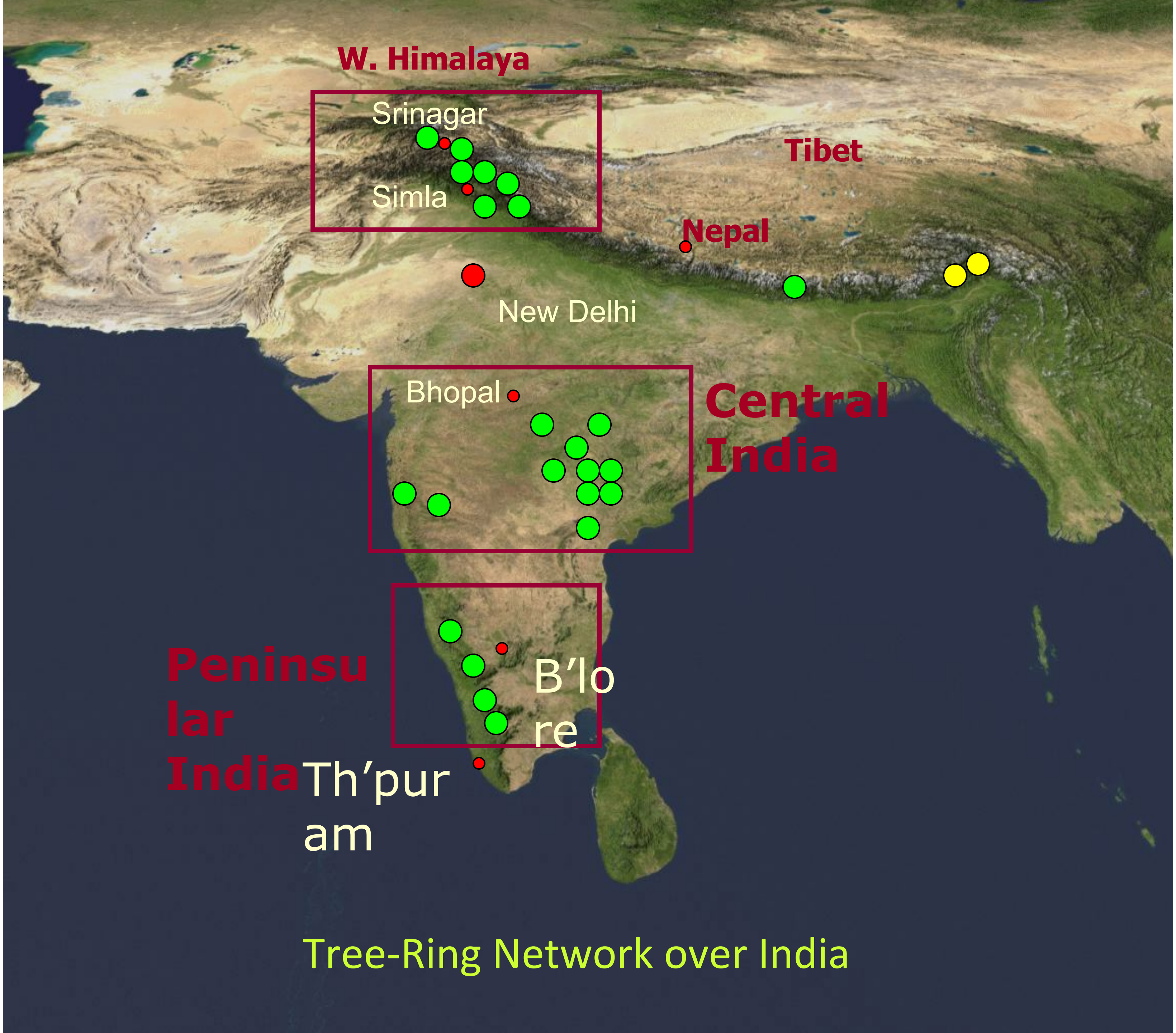


Kadapa
(a)
$\delta^{18}O$ ‰
−4
−6
−8
DRY
WBOB
(b)
$\delta^{13}C$ ‰
−24
−25
−26
−27
NAS
(c)
Varve Tickness
0.50
0.75
1.00
1.25
1.50
Baratang
(d)
$\delta^{18}O$ ‰
−3
−4
−5
−6
−7
WET
3000
2500
2000
1500
1000
500
0
Years in BP



MWP
RWP
DACP
MCA
LIA
SE IO SST Anamoly (°C)
(a)
(b)
N Atlantic SST (°C)
(c)
Cariaco Titanium %
(d)
ENSO index (No. of events/100 yr)
(e)
GSIP SST (°C)
(f)
Solar Insolation (W/m2)
Atmospheric Δ14C (‰)
Age yr BP

Dendroclimatic reconstruction studies in IITM

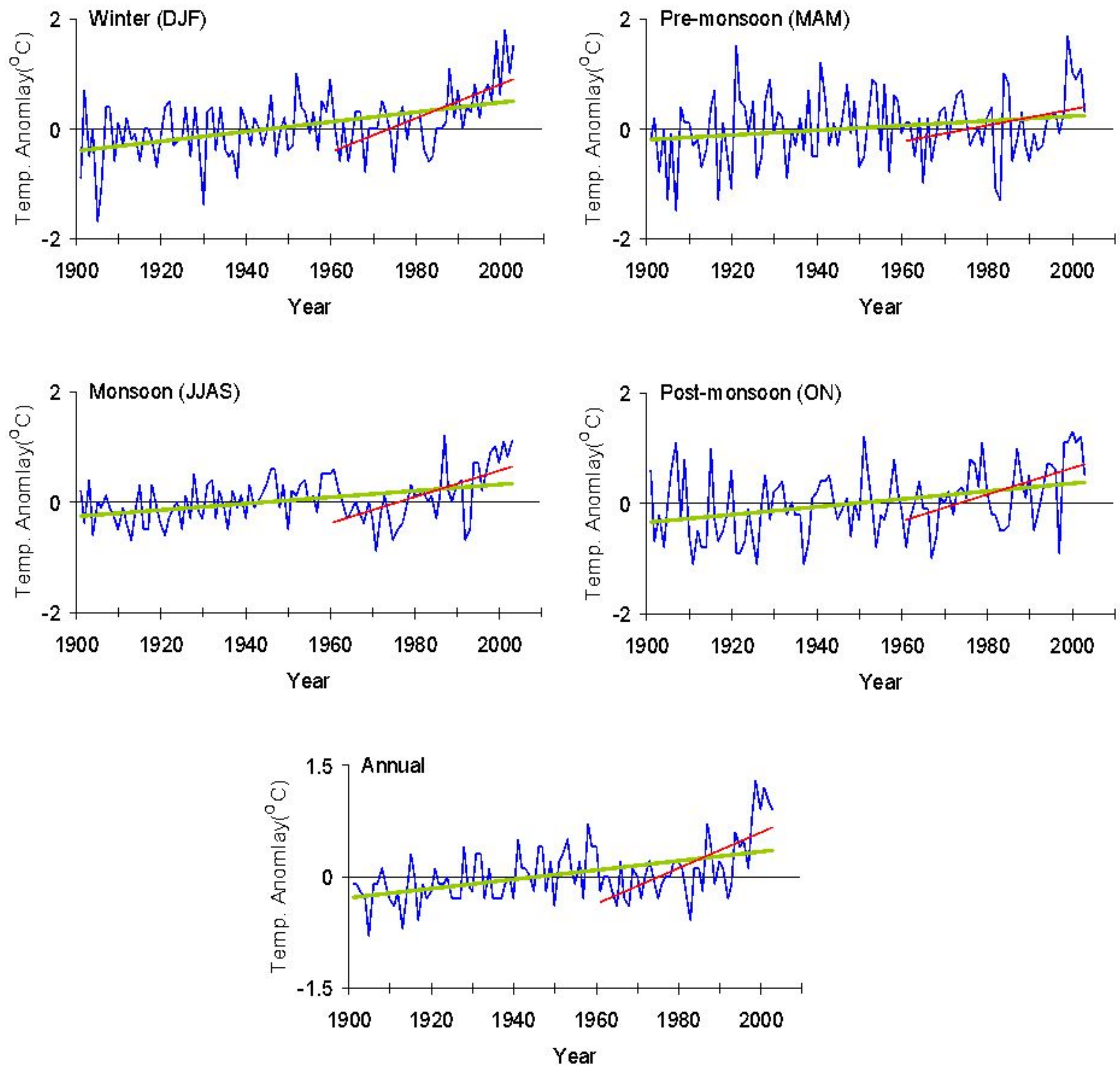


Tree-Ring Network over India

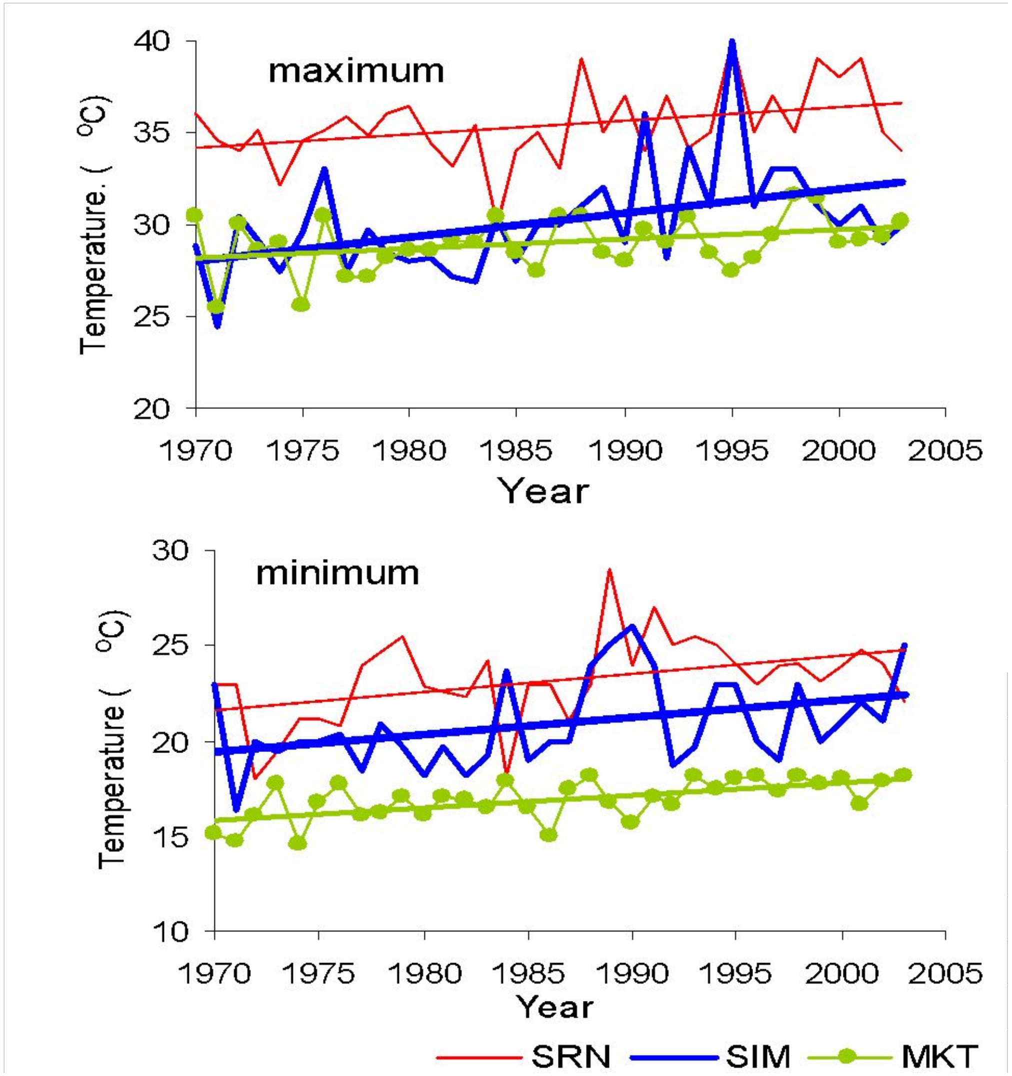
- ***<u>The Himalaya</u>*** :
  the greatest mountain barrier on the earth where polar, tropical and Mediterranean influences interact.

- Varied climate ranging from dry cold desert, moist temperate, wet temperate to sub-tropical.

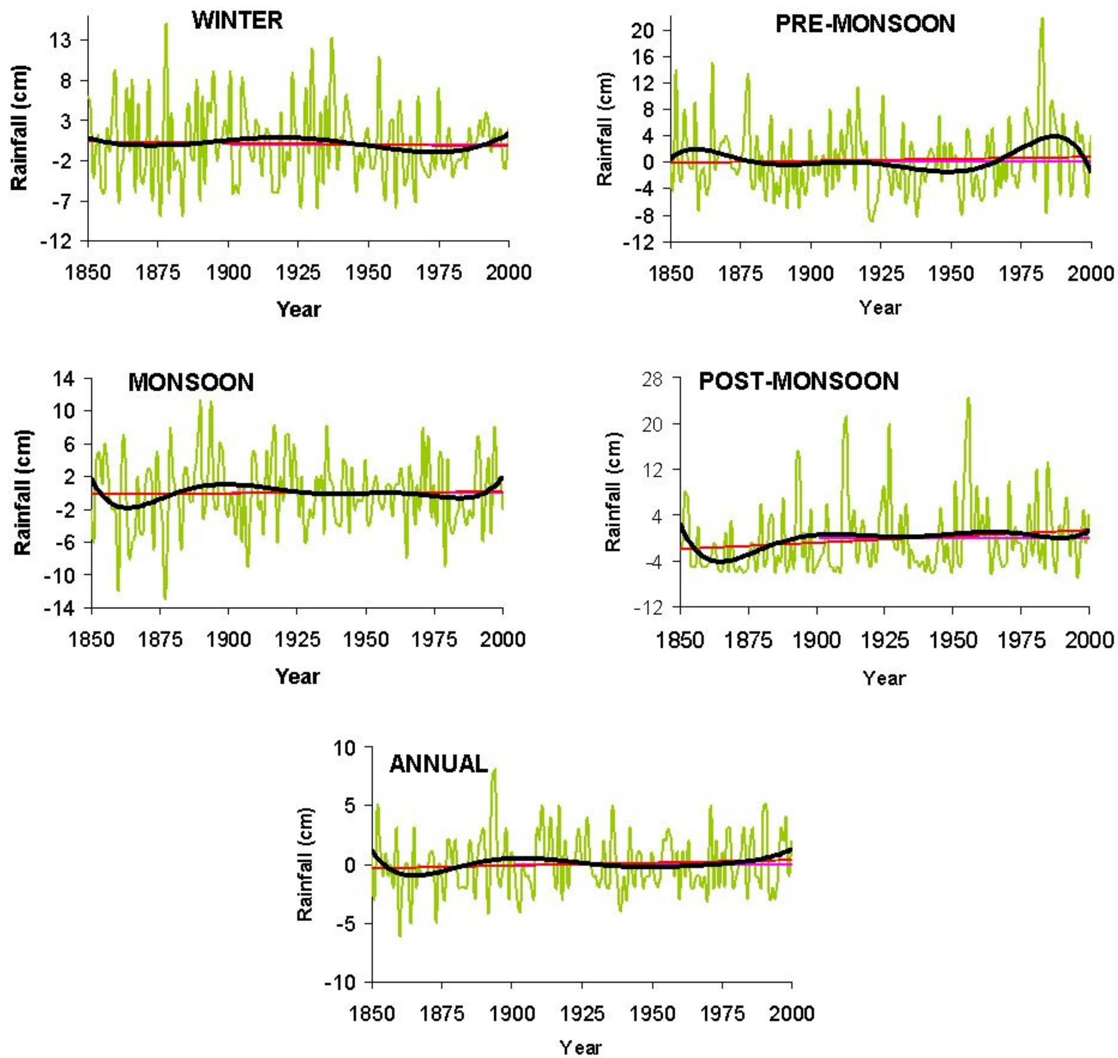
- **Forest types**
  - subtropical Forest
  - temperate Forest
  - Subalpine Forest
  - Alpine Forest.



Mean surface temperature series over Western Himalaya for different seasons with trend lines (green bold lines for entire series, red lines for recent four decades).



Annual highest values of daily maximum and minimum temperatures of Srinagar (SRN), Shimla (SIM) and Mukteswar (MKT) for the period 1970 to 2003.



Seasonal rainfall anomalies over Western Himalaya. Smooth lines indicate low-frequency variations.

Response function analysis (Monthly) showing response function eleme
significant at +% level. (□ *negative relationship; + positive relationsh*

Kashmir valley Middle Altitude (Northern Latitudes)

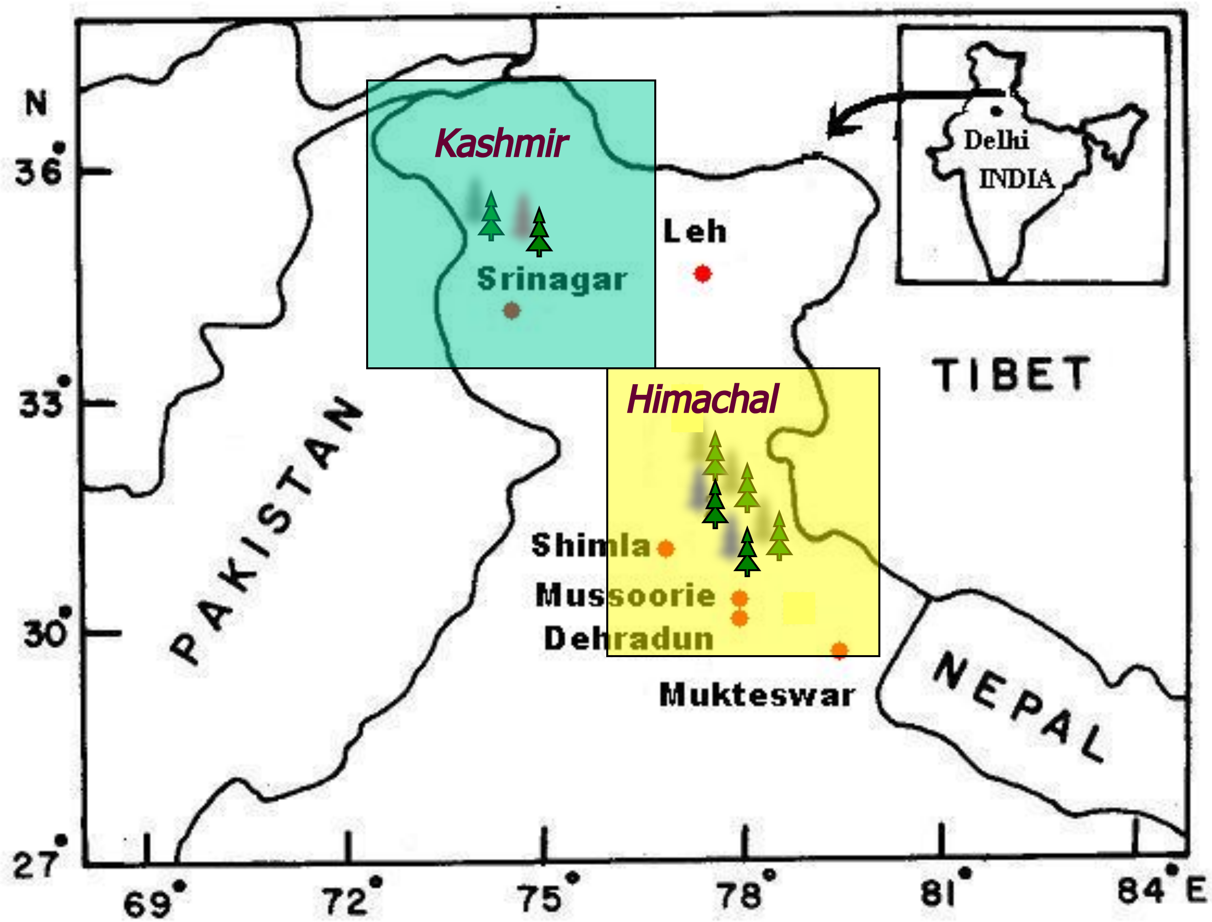
	Temperature													Precipitation												
ID	-O	-N	-D	J	F	M	A	M	J	J	A	S	O	-O	-N	-D	J	F	M	A	M	J	J	A	S	O
PHAAP		+	+			+		●	●	●						+	+		+	+	+	+	+	+	+	
PHAPS	+	+						●	●	●	●	●					+		+		+		+	+	+	●
GULAP		+		●	+	+			●	●	●	●								●	+	+	+			●
PARCD					+				●	●		●									+	+	+	+	+	
KNZAP	+	●	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

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	+	+	+	+	+			●				●	+		+	●	●		+		+				●	+

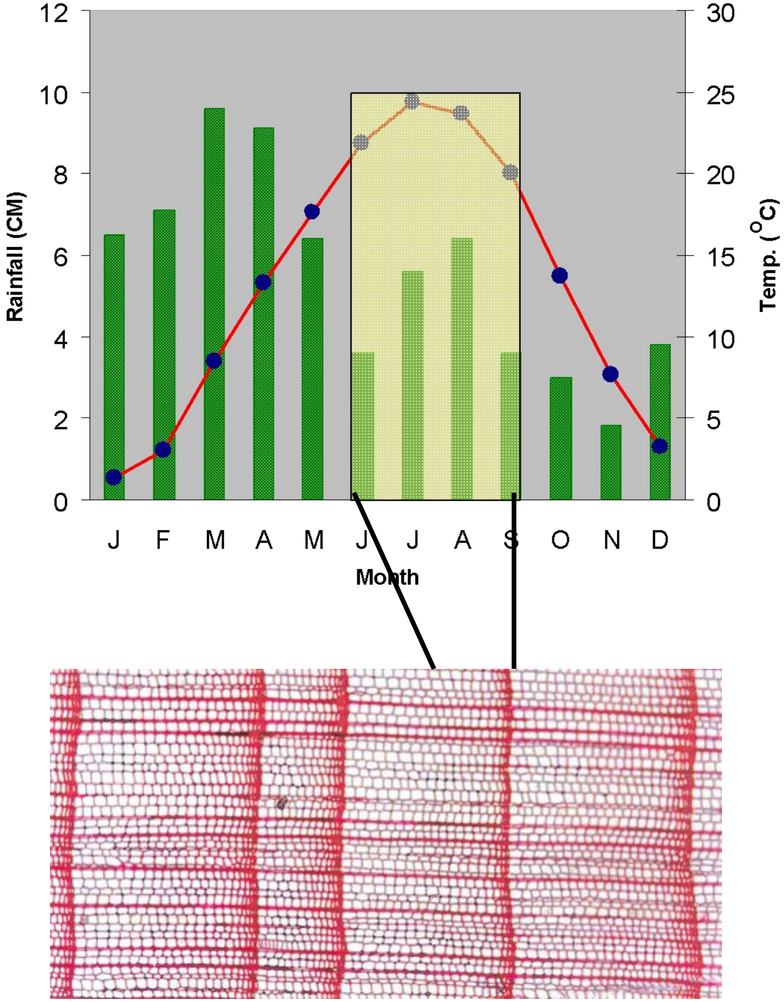


Location Map of Tree-ring Sampling Sites.

(1) Kashmir, (2) Himachal

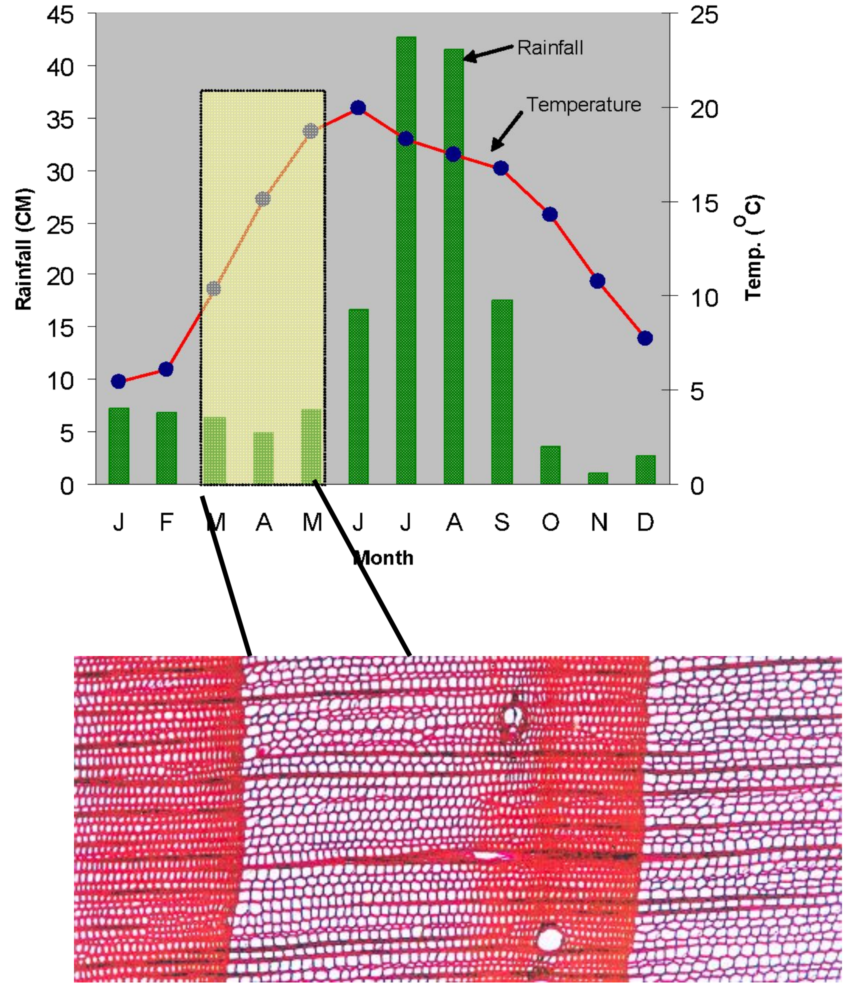
● Meteorological Stations

Kashmir Response



Abies pindraw

Himachal Response

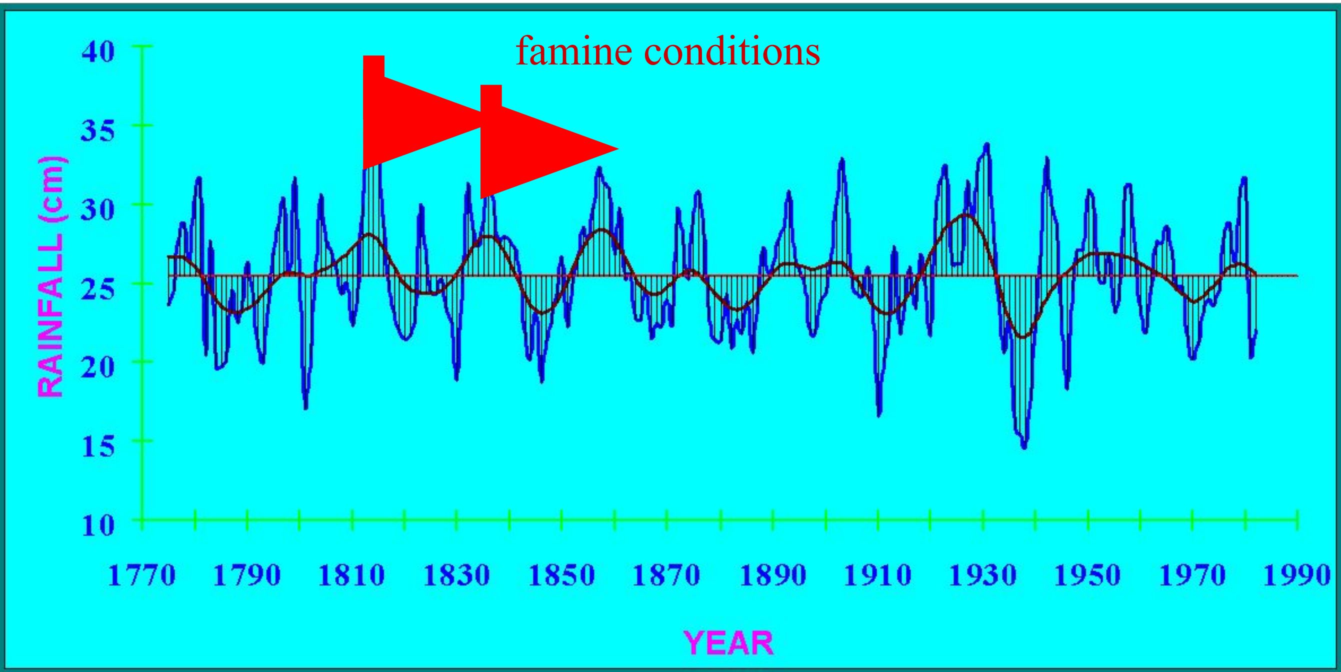


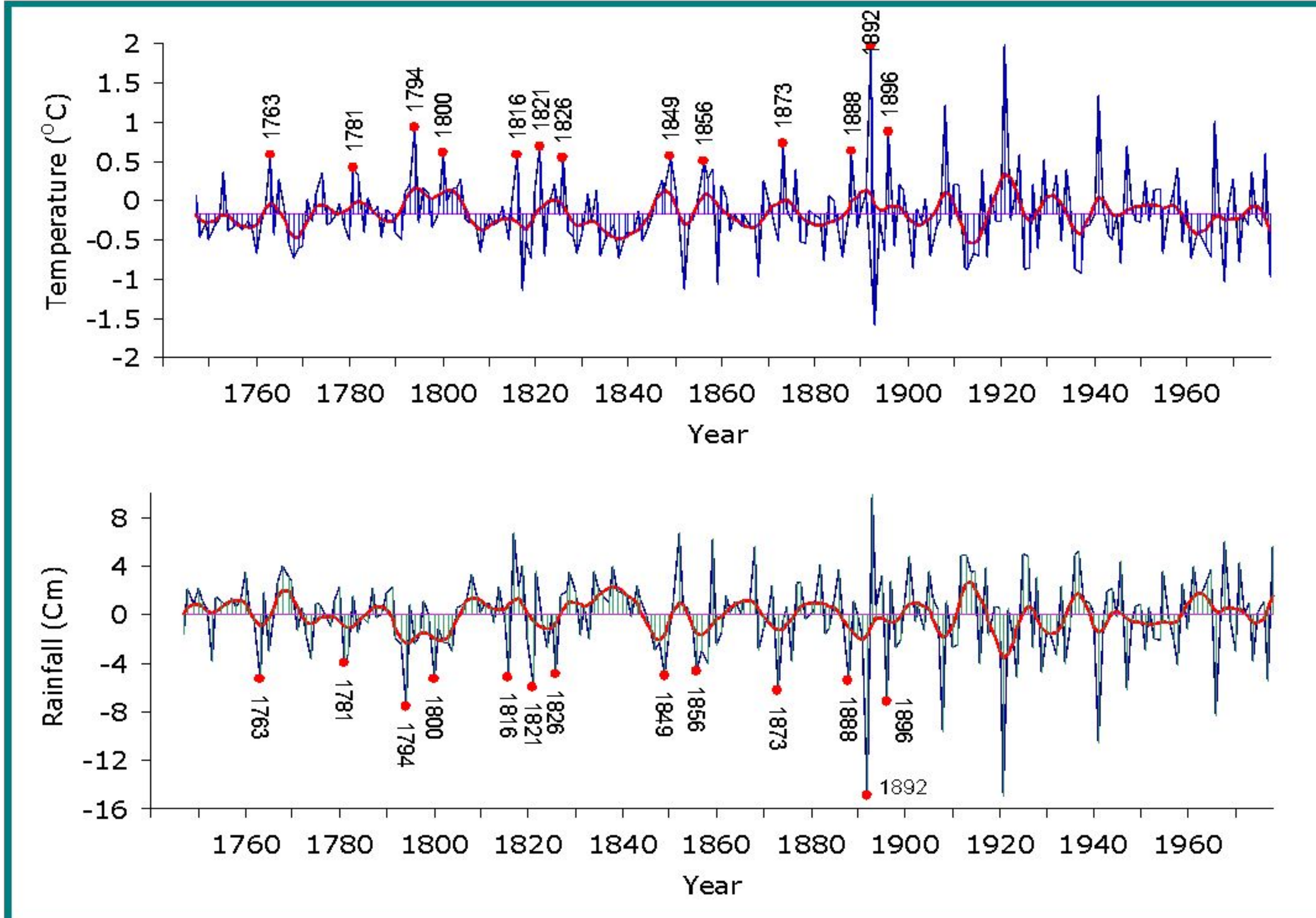
Cedrus deodara

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.

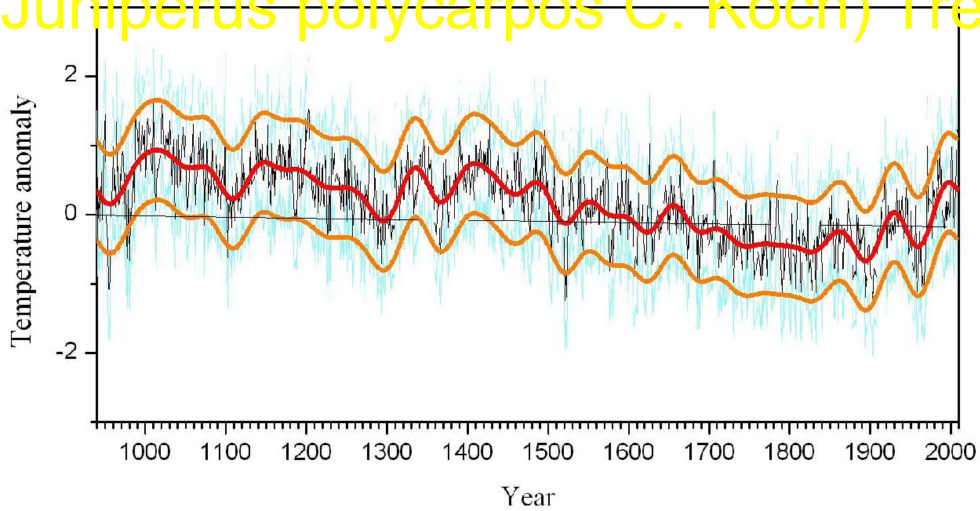




Western Himalaya Summer Climate (MAM) Reconstruction from multi-species tree-ring width chronologies (Borgaonkar et al. 2000)

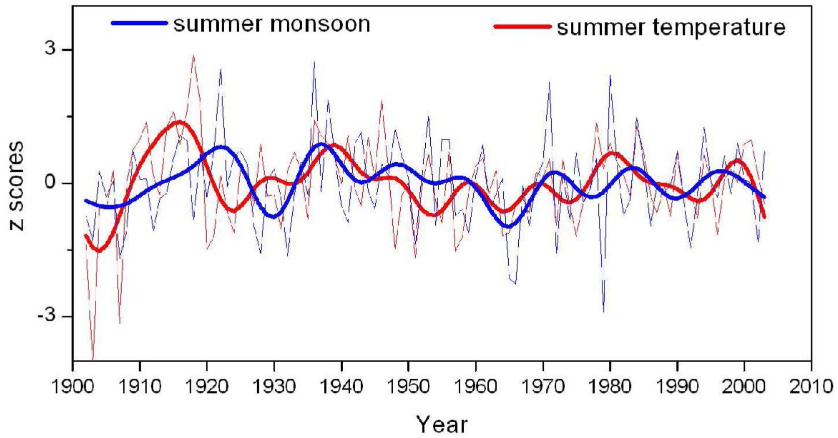
SUMMER TEMPERATURE VARIATIONS OVER THE LAST MILLENNIUM IN WESTERN HIMALAYA, INDIA [Juniper (Juniperus polycarpos C. Koch) Tree-Ring

(Yadav et al., 2009)

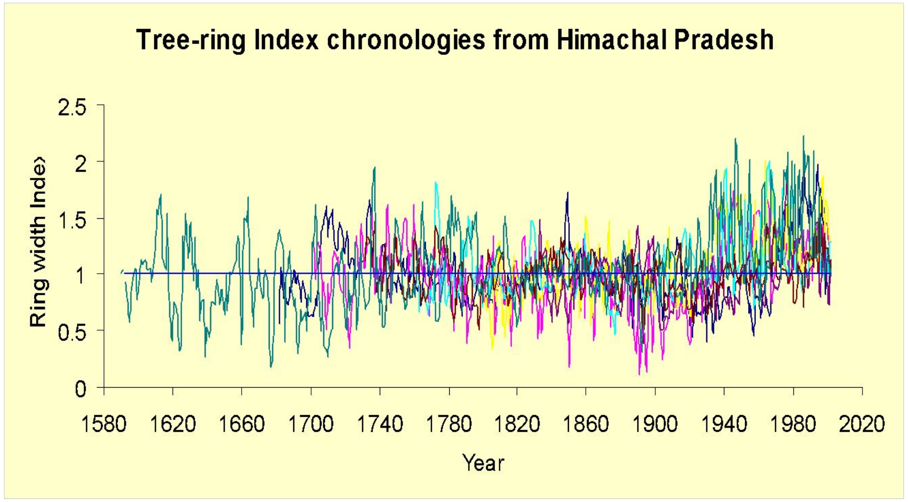


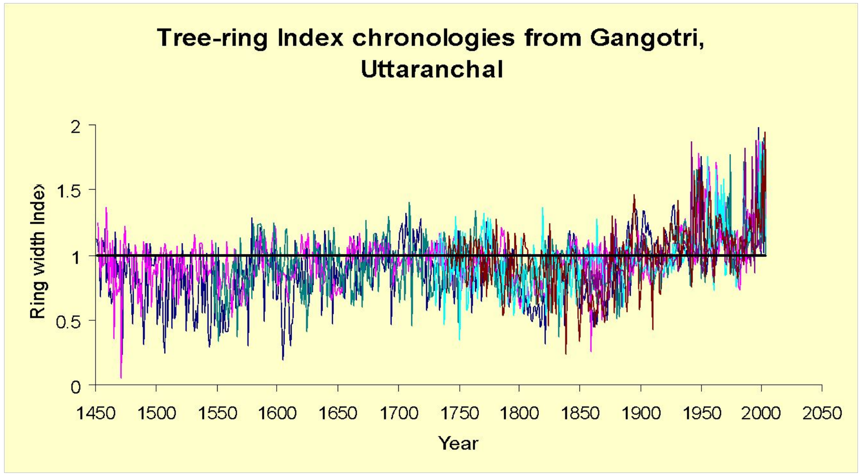
Mean annual summer (MJJA) temperature reconstruction for the western Himalaya (AD 940-2006). Reconstruction as well as lower and upper one standard errors were smoothed using 50-year low pass filter.

Detrended mean summer temperature (May-August) and summer monsoon precipitation series (June-September) over the north central India after 10-year low pass filtering.



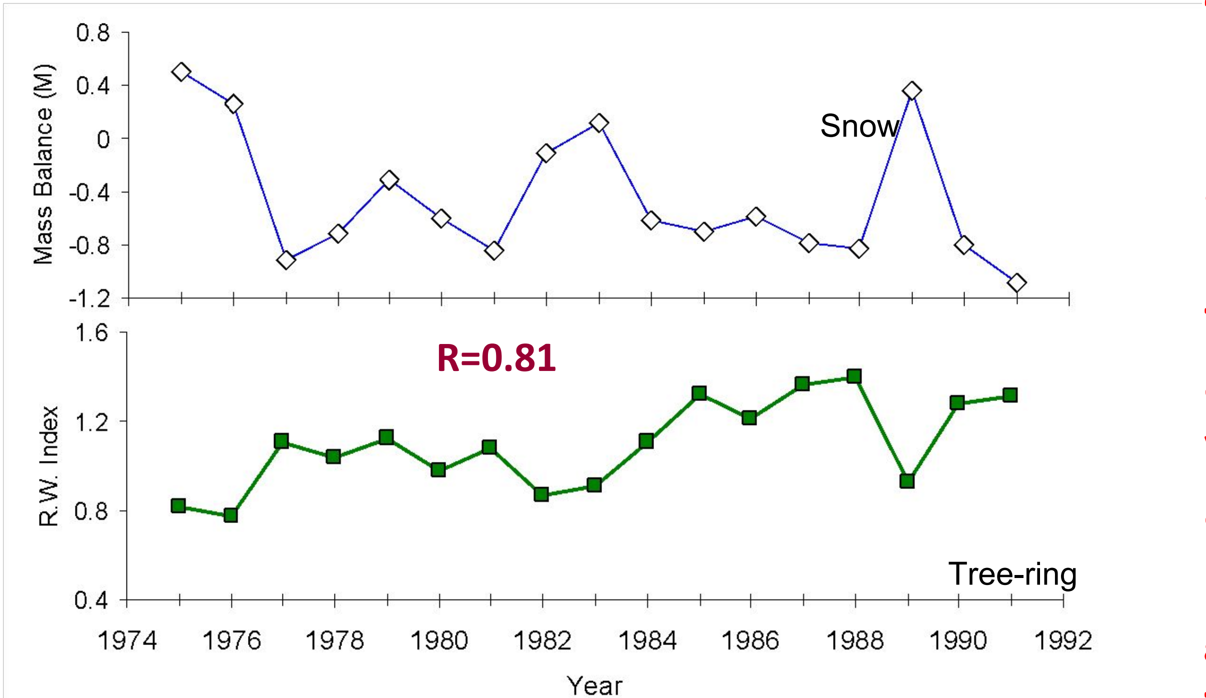
High altitude tree-ring chronologies from Western Himalaya

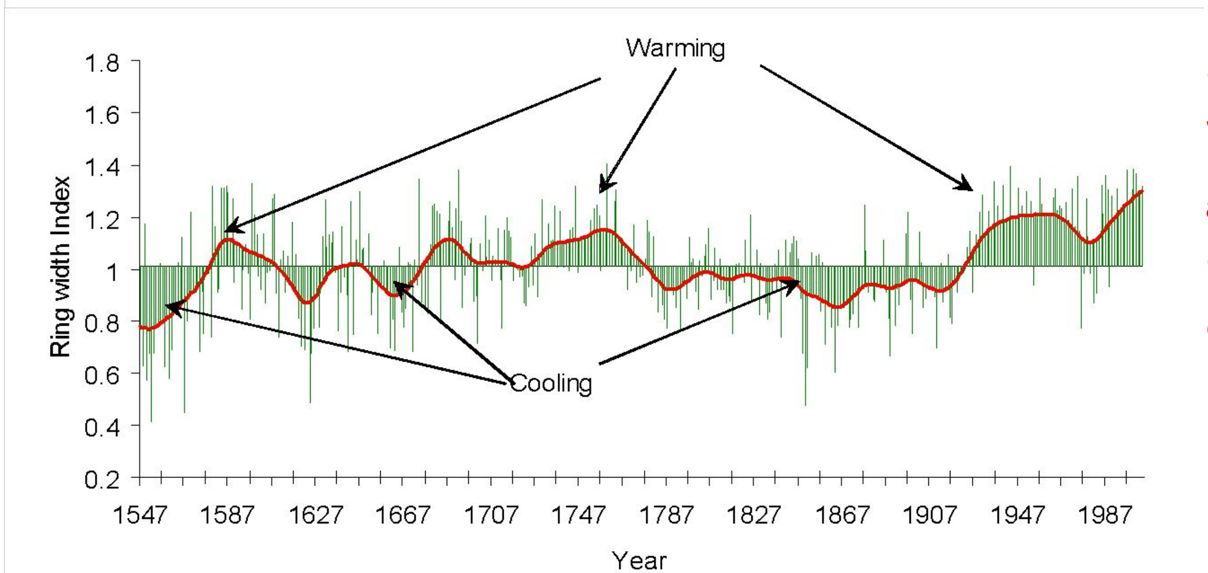




Kinnor, W.H. India, 3200 M amsl

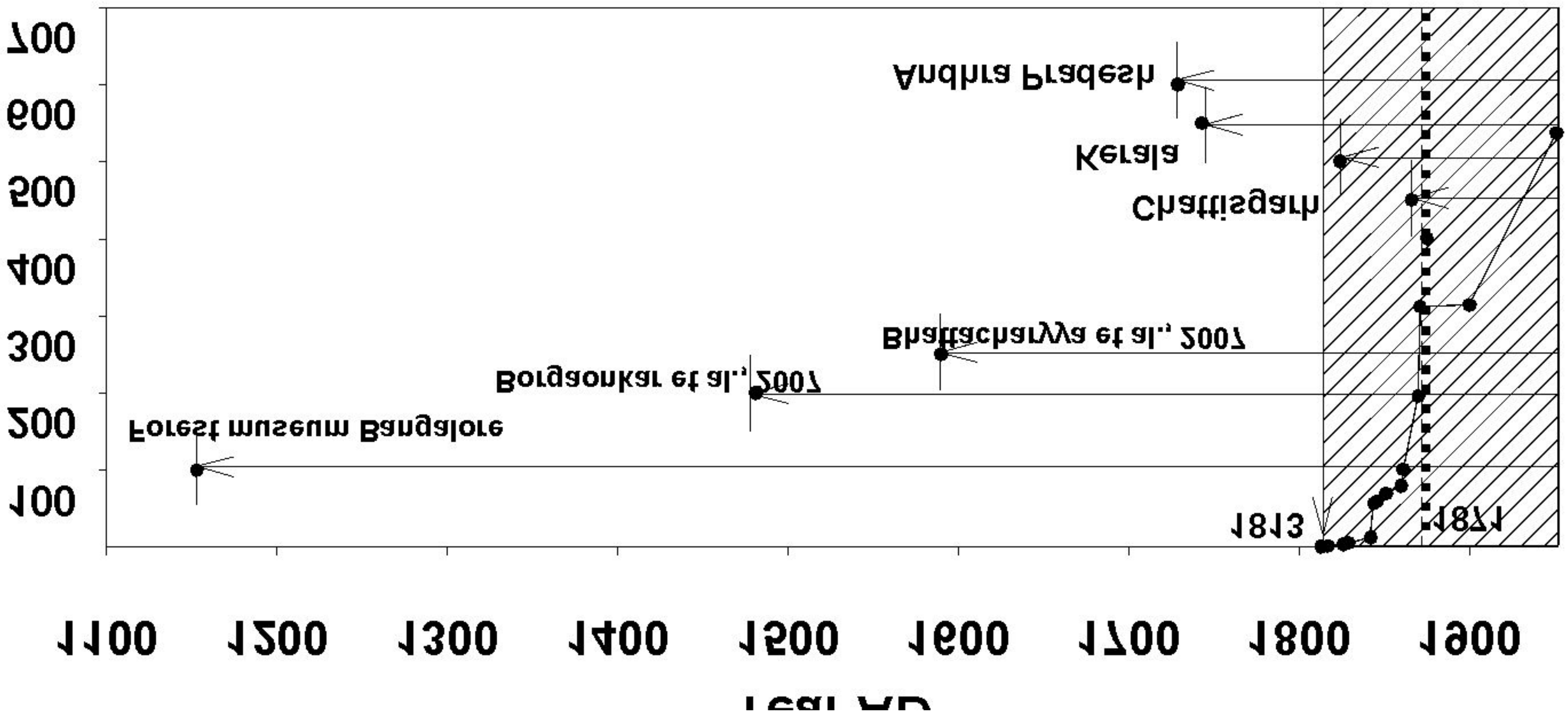
Gangotri, W.H. India, 3000 M amsl





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)

Indian teak record



Gaint teak (*Tectona grandis*) from Tokawada forest, Jagdalpur, Chattisgarh

Gaint Teak (Biggest in Asia)

Kappayam, Malayatoor,
Kerala, South India

Girth at breast height : 7.2 M

Gaint Teak
(Kannimara Teak)

Site :
Parambikulam,
Kerala, South India

Girth at breast
height : 6.52 M


KANNIMARA TEAK
MEASURMENT TAKEN ON....10.10.2002
GIRTH............................6.52 MTS
HEIGHT.........................4825MTS
CAN YOU FIND OUT MY AGE?
09/01/2004

Response function analysis showing the significant correlations between Teak tree-ring chronologies from central India and seasonal temperature & rainfall of corresponding nearest stations for the period 1901-2000

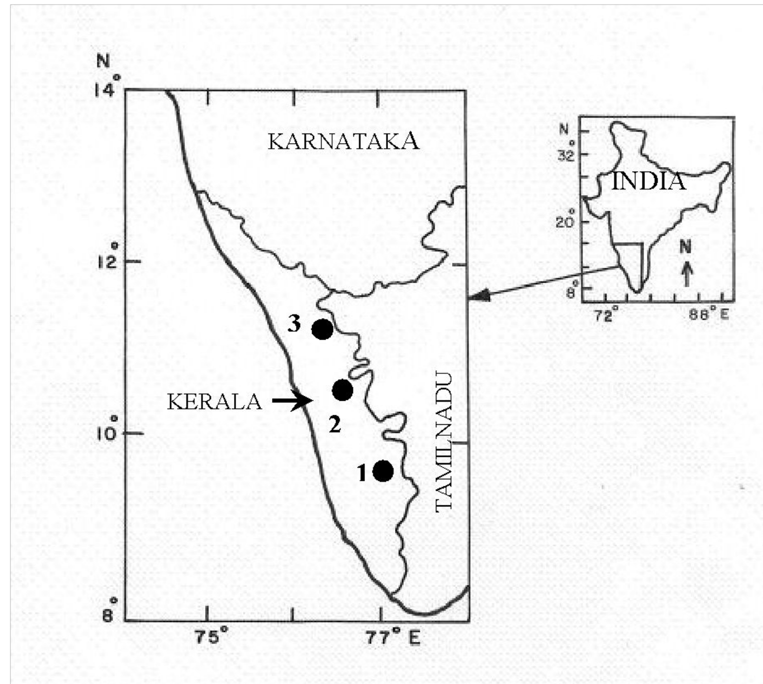
P < .05 (□ negative relationship; + positive relationship)

	Temperature						Rainfall					
MONTH → ID↓	-JJAS	-ON	DJF	MAM	JJAS	ON	-JJAS	-ON	DJF	MAM	JJAS	ON
KUR	+			●	+		+		●	+	+	●
BHO		●	+	●				●			+	+
BOR		●		●				●	●	+	+	
TOL	+			●		●			●	+	+	
DHA				●	●			+			+	●
NAG					●	+	●			+		
BAM		+	●	●				+	●	+	+	
ALA				●		●			●	+	+	●
EDU				●				●	●	+		
CHI		+	●	●				●			+	+

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)

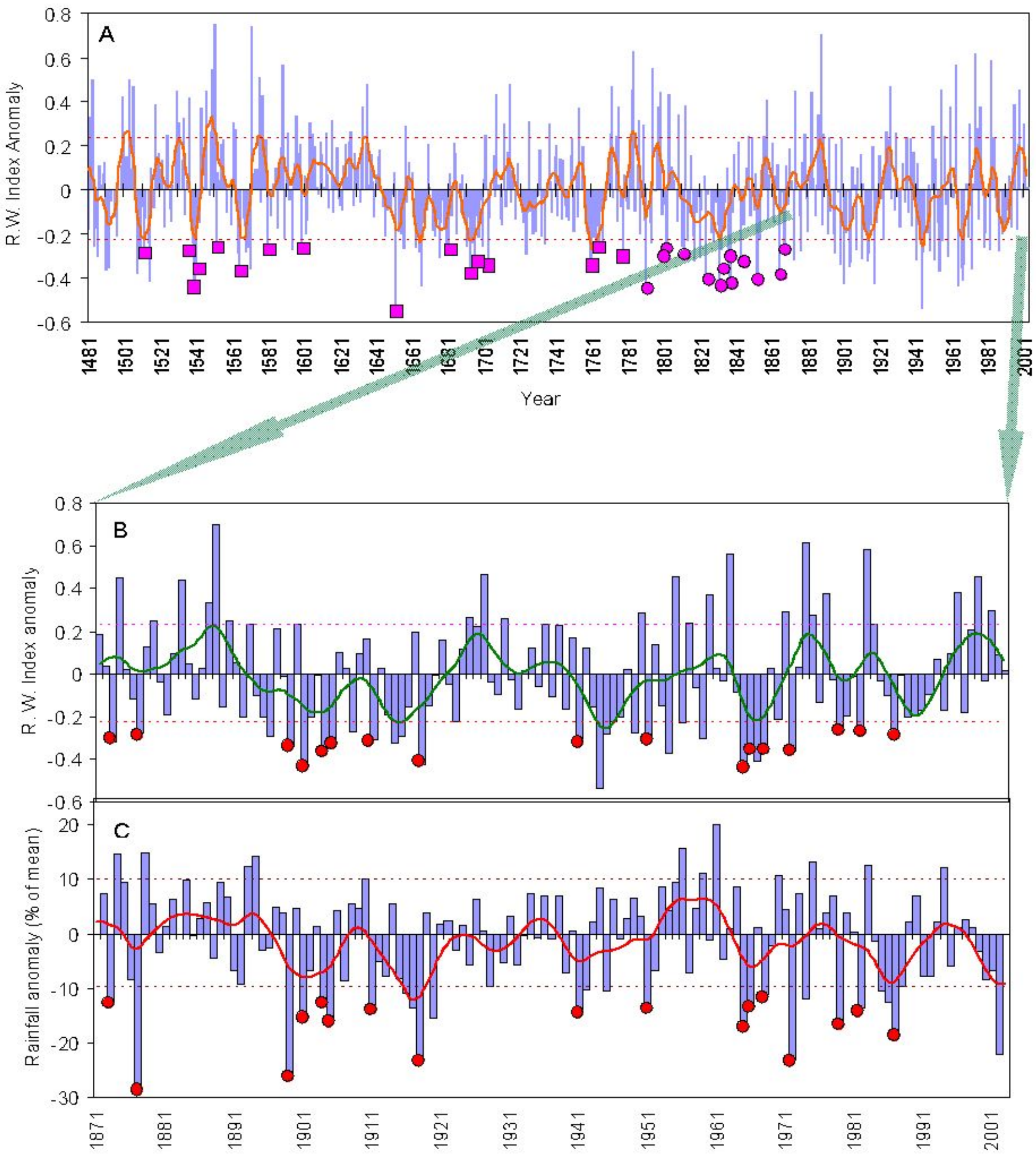


Locations of the Tree-ring sites. 1 : Tekkady (TKD); 2 : Narangathara (NAR); 3 : Nellikooth (NEL).

(Palaeo-3; Borgaonkar et al. 2010)

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.

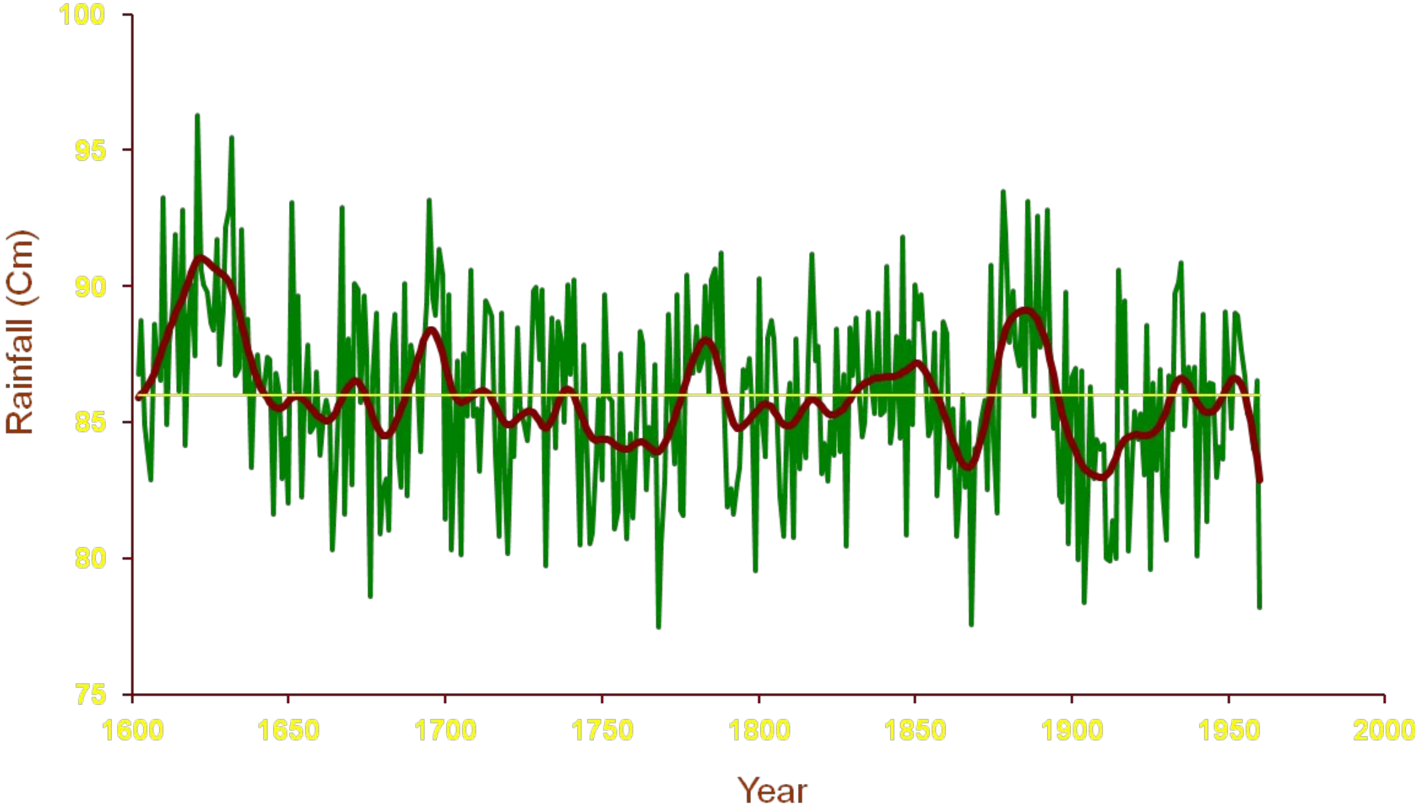
(B and C) KTRC and ISMR anomalies respectively during the instrumental period 1871-2003. Red circles in fig. B are low growth years and have one to one correspondence with deficient monsoon rainfall (drought) years associated with El Nino shown as red circles in fig. C.

Occurrence of Low Growth Years (LGY) in Deficient Indian Rainfall (DIR) associated with El Nino events during Instrumental (I), Historical (H) and Reconstruction (REC) period.

	H+I (1791-1987)	H (1791-1870)	I(1871-1987)	REC (1525-1790)
LGY	46	19	27	34
DIR	30	13	17	17 (Reconstructed)
Asso. El Nino	30	13	17	17
% of LGY	66%	68%	63%	50%
LGY with El Nino but No DIR	9	5	4	----
LGY with No El Nino & No DIR	7	1	6	----

REC period is prior to historical period (i.e. < 1791) where only tree-ring and El Nino data available and DIRs have been reconstructed.

All India summer monsoon rainfall series since A.D. 1602-1960. Reconstruction from tree-ring based SOI.



Drought years as reflected in the reconstructed AISMR series

1664, 1676, 1679, 1703, 1717, 1724, 1732, 1743, 1767, 1769, 1791, 1799, 1803, 1806, 1812, 1833, 1865, 1868

Tree-ring climate products (World wide)

- Global Temperatures (NH) 1000 Years.
- Continental Temperature 2000 Years
- Regional and Local Temperature and precipitation (N. America, S. America, Europe, Asia, Australia) 1400 years.
- Droughts, PDSI : 400 Years
- SST, El Nino : 350 years
- Fire History : 400 years
- Glacier Movement : 600 years
- Himalaya Temperature: 500 years
- Indian monsoon drought records: 500 years