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Impacts of Climate Variability and Climate Change on Agricultural Productivity in South Asia

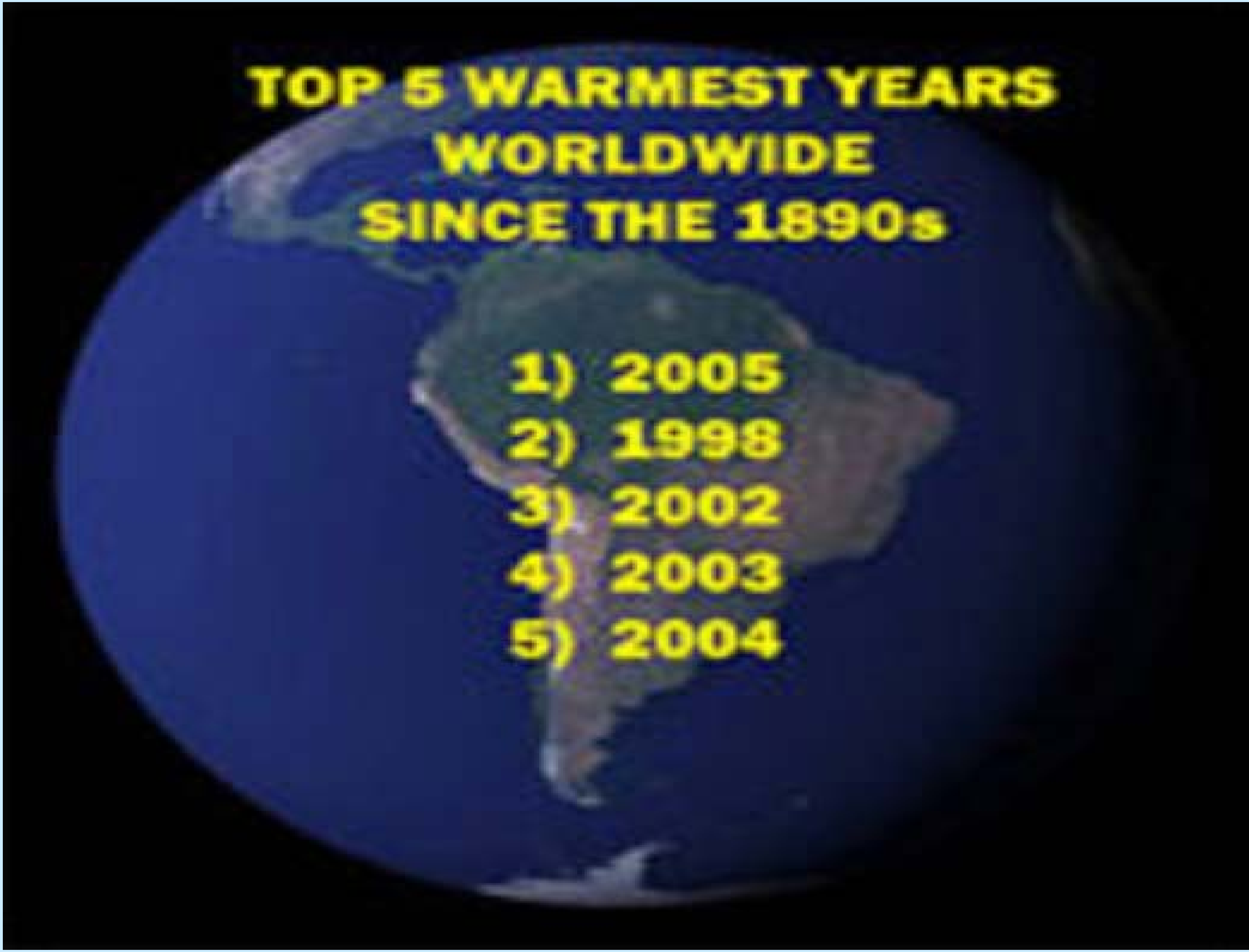
M. Lal

The University of the South Pacific

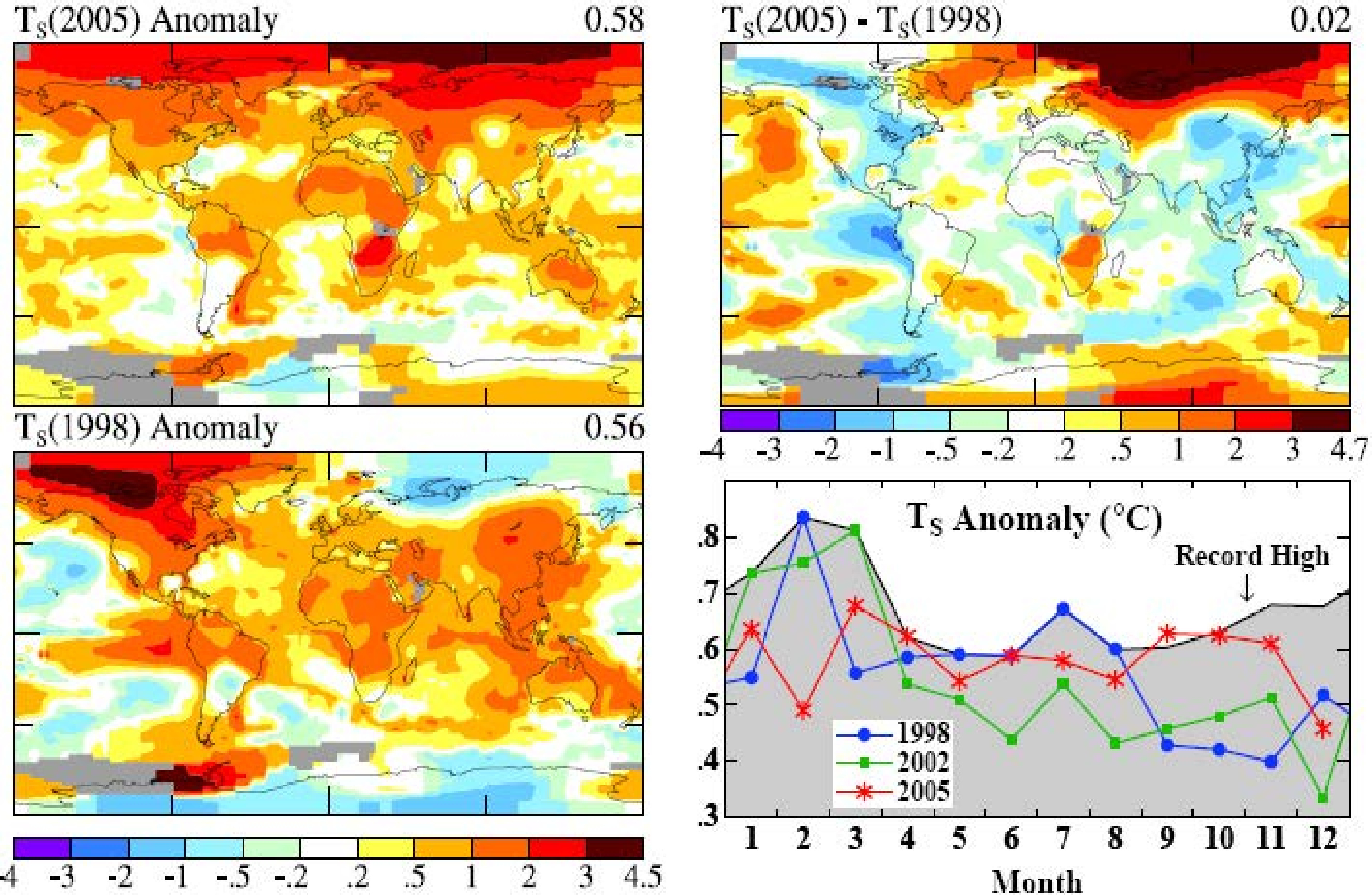
The Year 2005 recorded the highest mean annual average surface temperature since instrument recordings began in the late 1800s.

The year 2005 reached the warmth of 1998 without the "El Nino of the century" that pushed temperatures up in 1998.

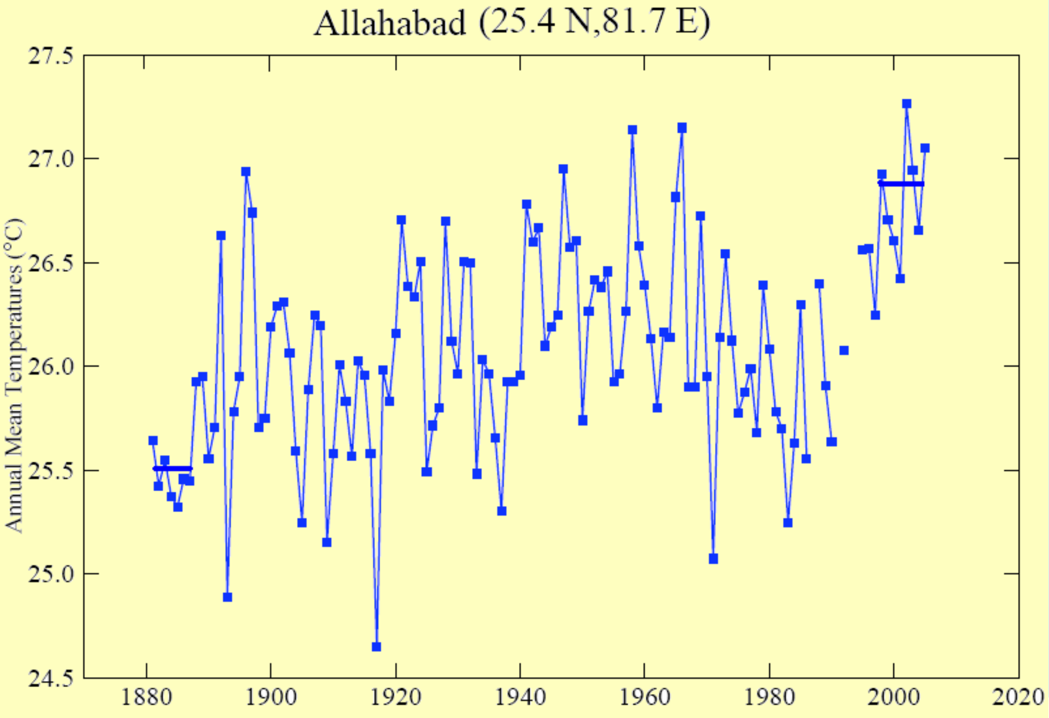
Over the past 30 years, Earth has warmed close to about 1^{o}C, making it about the warmest in 10,000 years due to buildup of greenhouse gases.

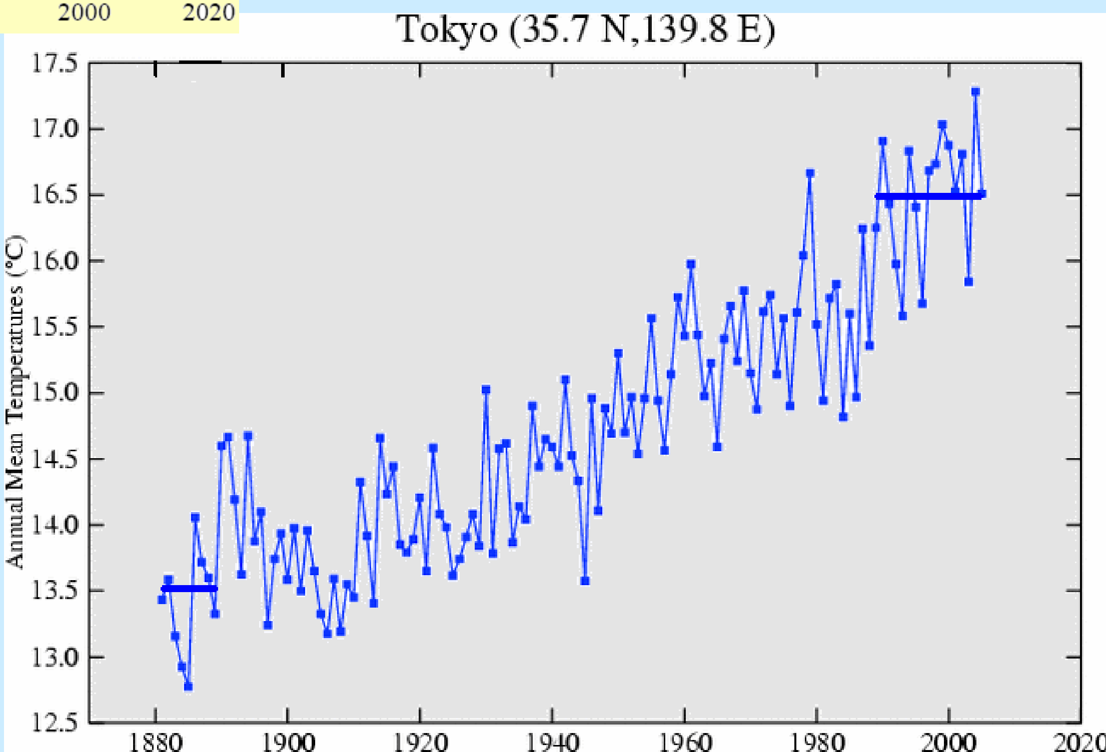

TOP 5 WARMEST YEARS
WORLDWIDE
SINCE THE 1890s
1) 2005
2) 1998
3) 2002
4) 2003
5) 2004

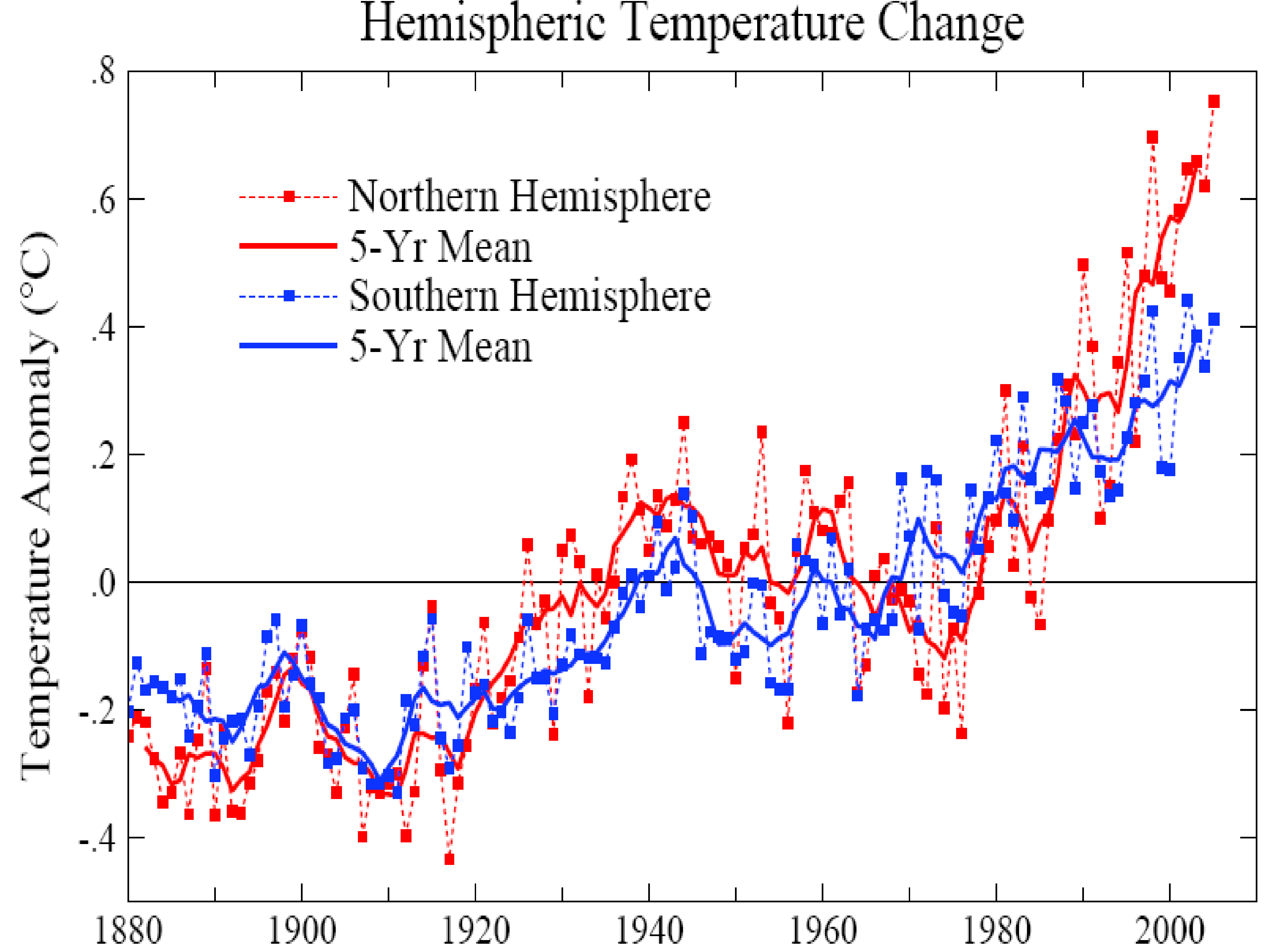
Comparison of 1998 and 2005 January-December Mean Surface Temperature (°C)



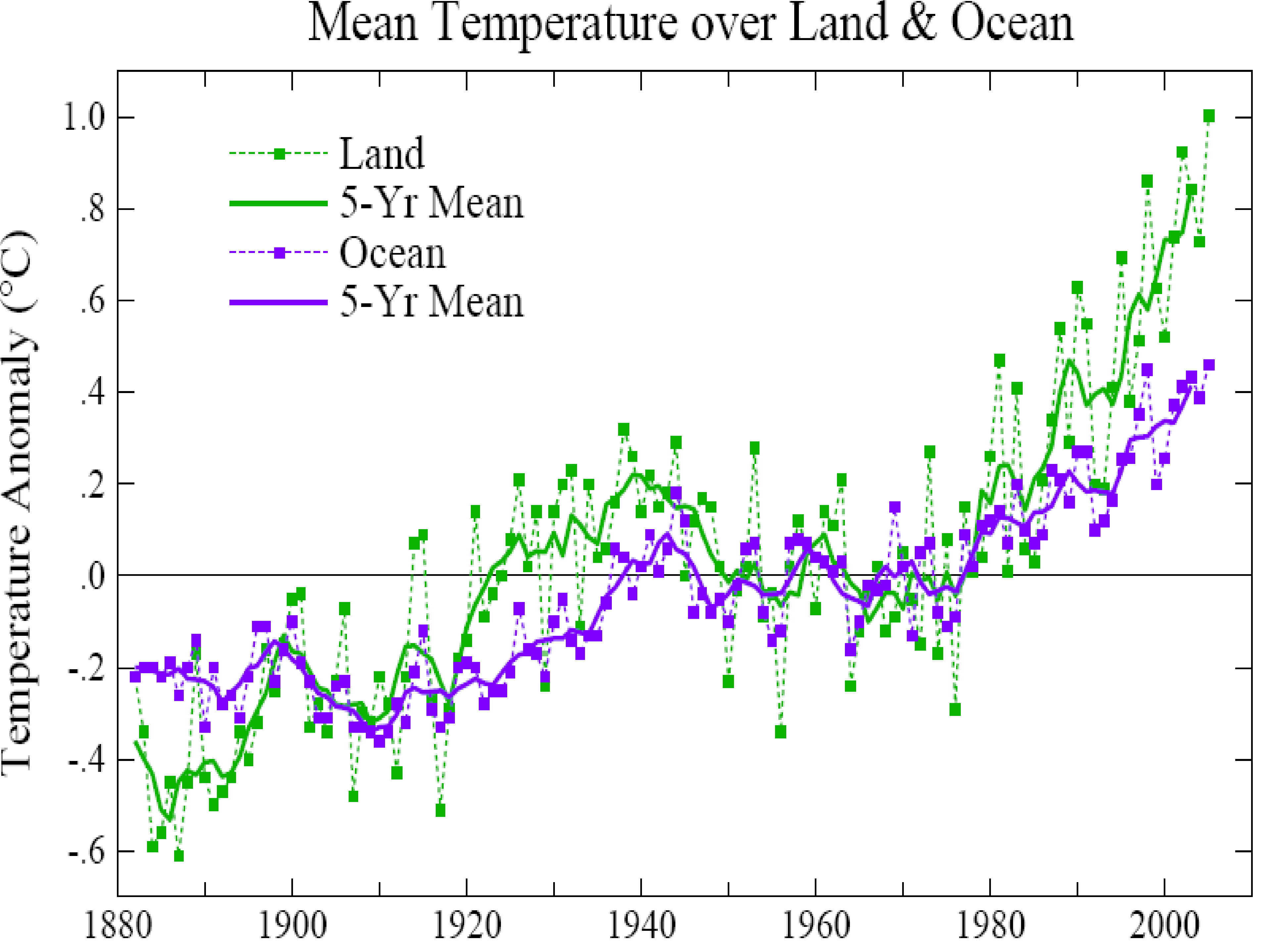
Base Period: 1951-1980


Allahabad (25.4 N,81.7 E)
Annual Mean Temperatures (°C)
27.5
27.0
26.5
26.0
25.5
25.0
24.5
1880
1900
1920
1940
1960
1980
2000
2020


Tokyo (35.7 N,139.8 E)
Annual Mean Temperatures (°C)
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
1880
1900
1920
1940
1960
1980
2000
2020



Hemispheric Temperature Change
Northern Hemisphere
5-Yr Mean
Southern Hemisphere
5-Yr Mean
Temperature Anomaly (°C)
.8
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000

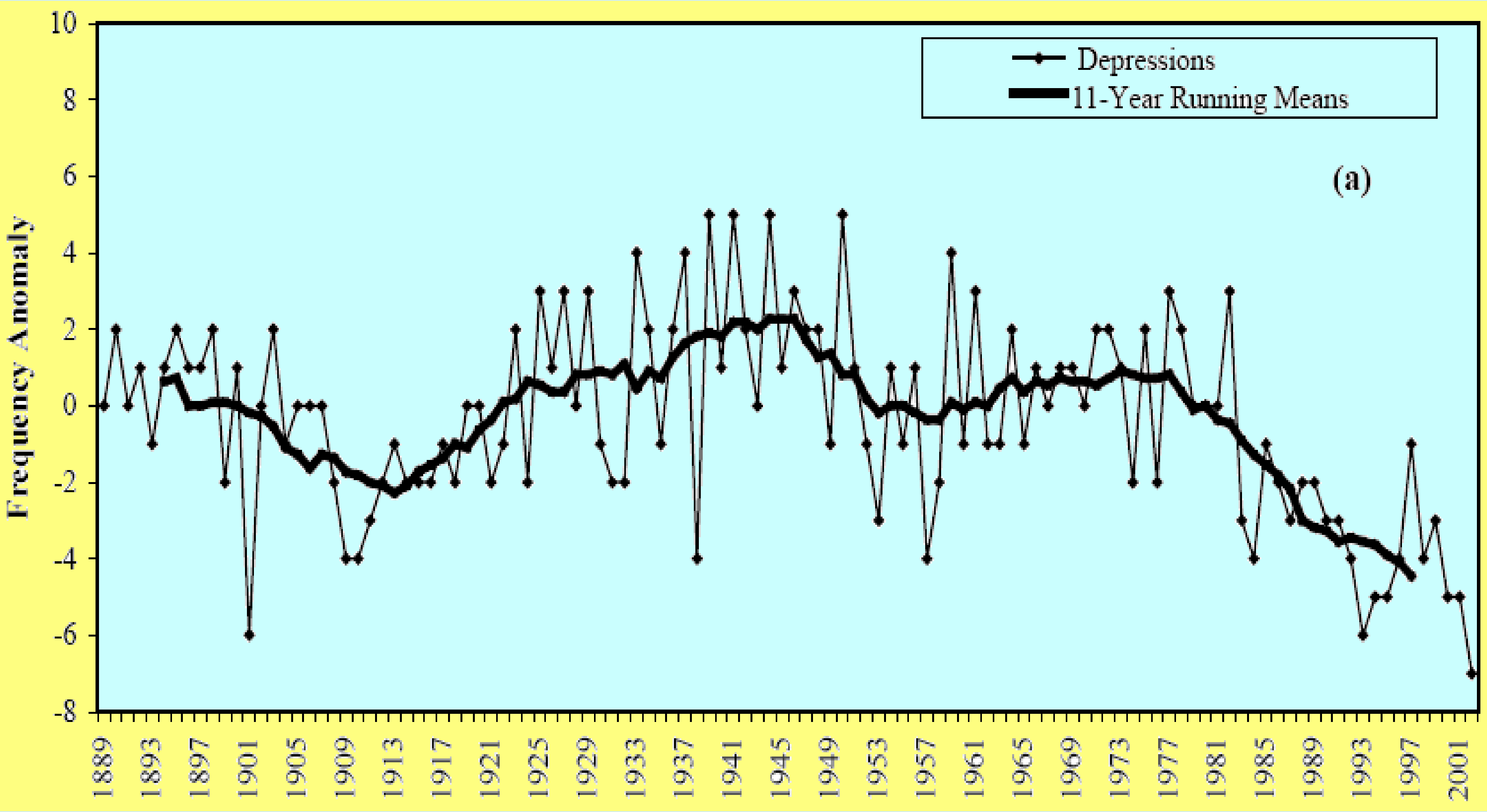

Mean Temperature over Land & Ocean
Land
5-Yr Mean
Ocean
5-Yr Mean
Temperature Anomaly (°C)
1.0
.8
.6
.4
.2
.0
-.2
-.4
-.6
1880
1900
1920
1940
1960
1980
2000

Changes in temperature (°C) during different seasons in India

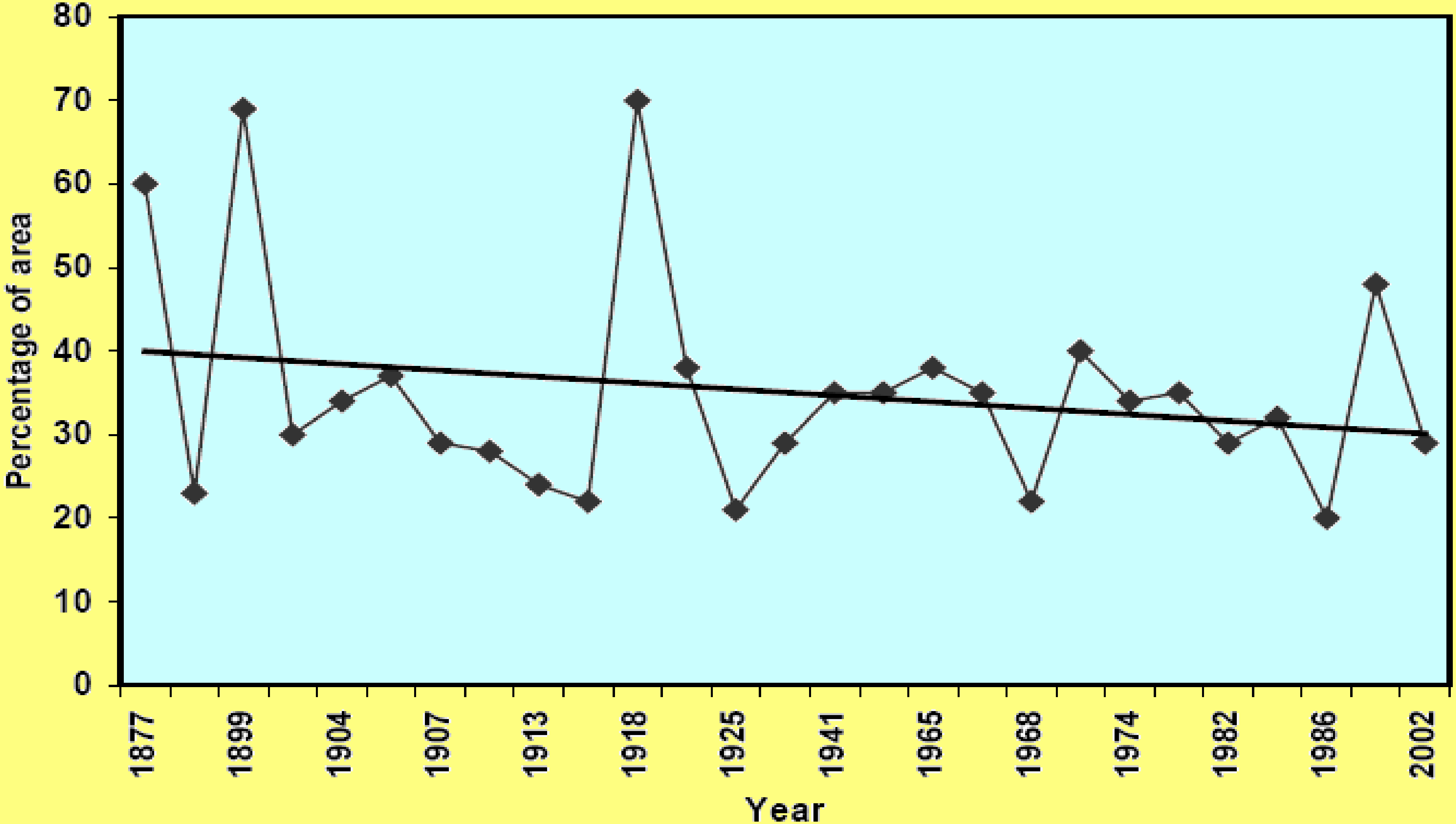
Period	Mean	Maximum	Minimum
Annual	0.7	0.6	0.15
Winter	1.0	0.8	0.05
Pre-monsoon	0.3	0.4	0.05
Monsoon	0.5	0.3	-0.2
Post-monsoon	1.0	0.8	0.4

Changes in temperature (°C) in different regions of India

Period	Maximum	Minimum
North West	0.45	-0.4
North Central	0.7	-0.2
North East	1.0	-0.2
Interior Peninsular	0.2	0.5
East Coast	0.55	0.25
West Coast	1.1	0.1

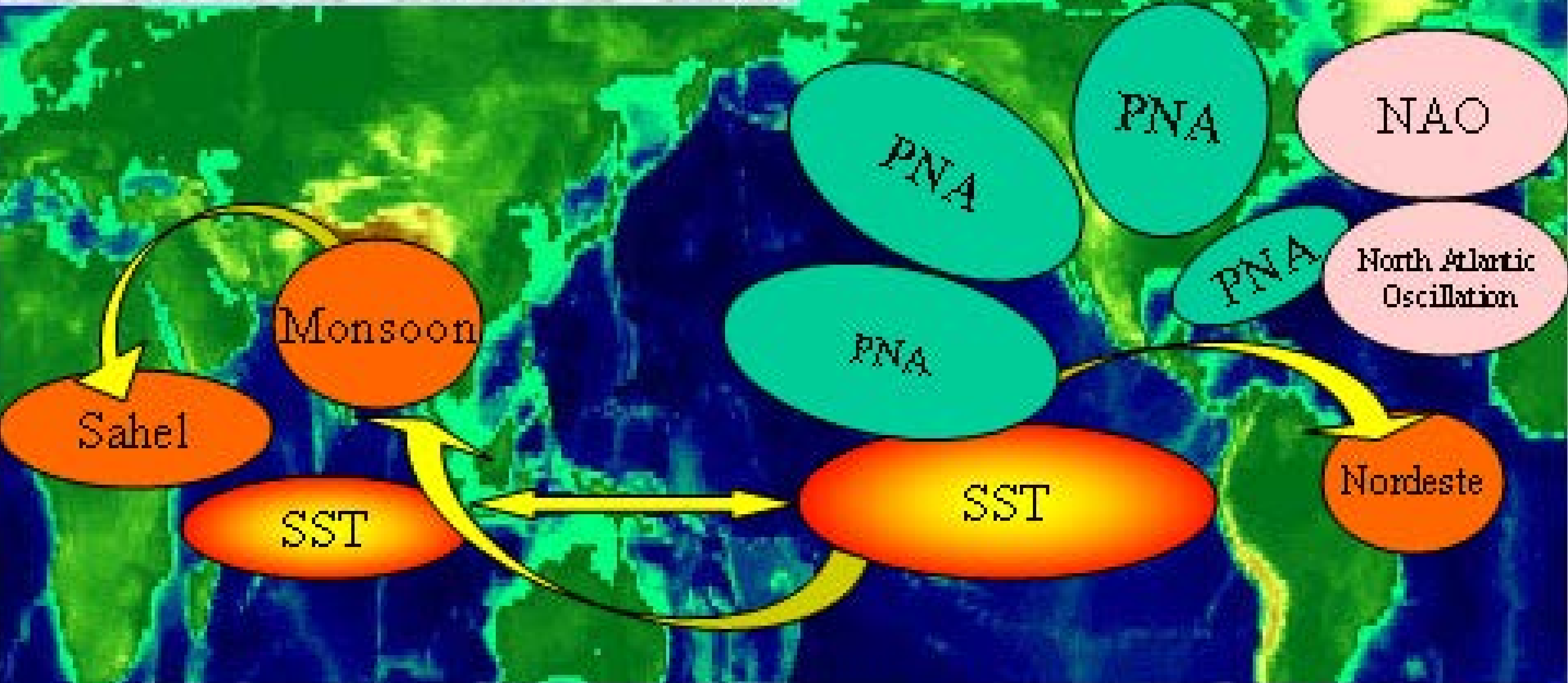


Depressions
11-Year Running Means
(a)
Frequency Anomaly
10
8
6
4
2
0
-2
-4
-6
-8
1889
1893
1897
1901
1905
1909
1913
1917
1921
1925
1929
1933
1937
1941
1945
1949
1953
1957
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
2001

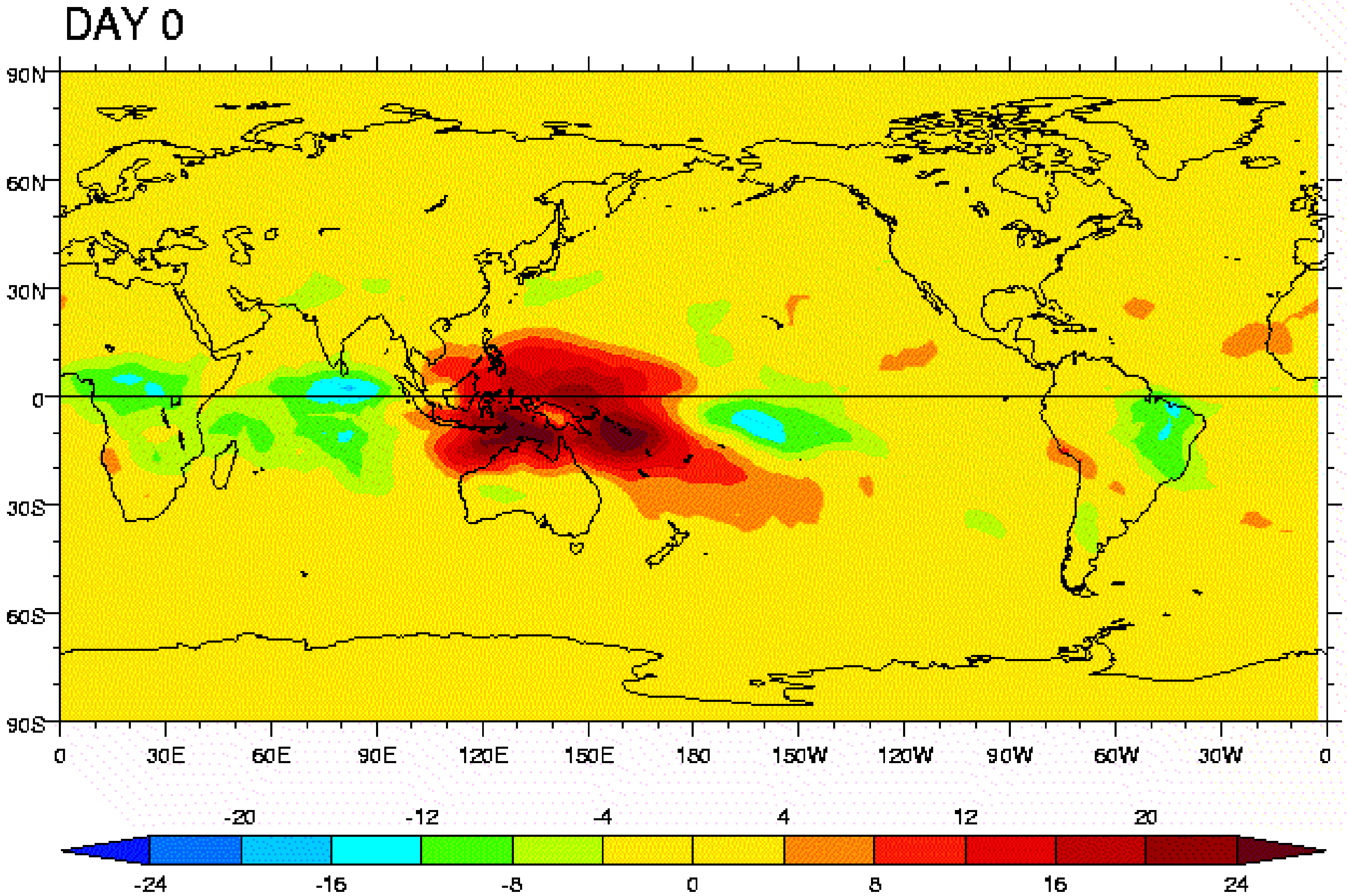


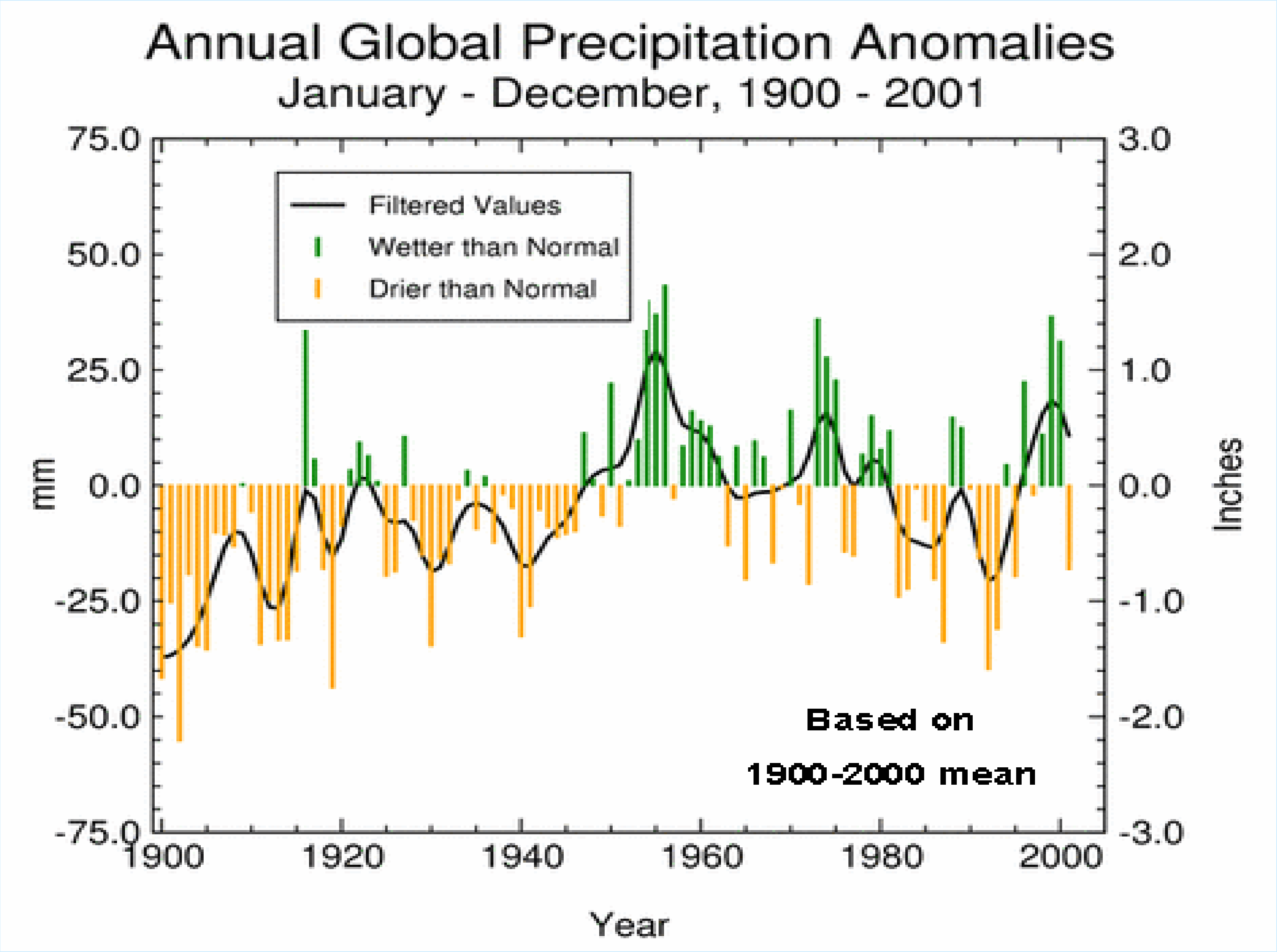
Percentage of area of the country under moderate and severe drought for the period 1877-2002.

Climate Variability



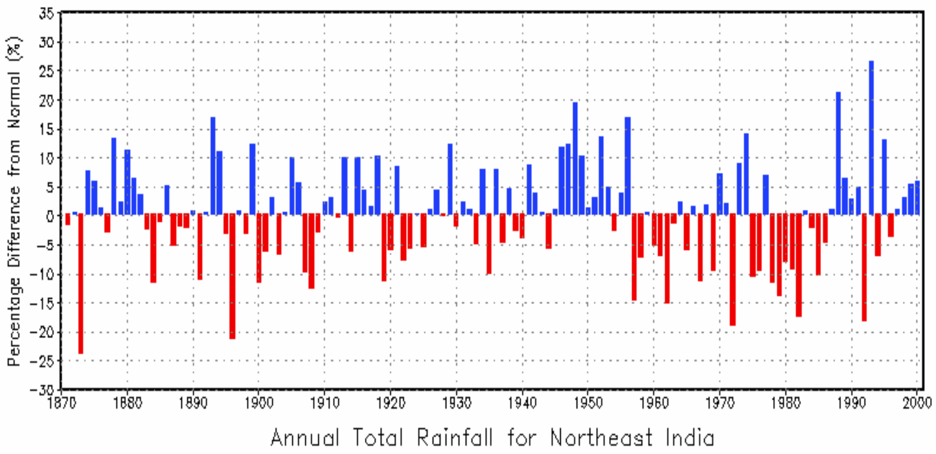
The interactions between atmosphere and oceans in the tropics dominate the variability at inter-annual scales. The main player is the variability in the equatorial Pacific. Wave-trains of anomaly stem from the region into the mid-latitudes, as the Pacific North American Pattern (PNA). The tropics are connected through the Pacific SST influence on the Indian Ocean SST and the monsoon, Sahel and Nordeste precipitation. It has been proposed that in certain years the circle is closed and and a full chain of teleconnections goes all around the tropics. Also shown is the North Atlantic Oscillation a major mode of variability in the Euro-Atlantic sector whose coupled nature is still under investigation.

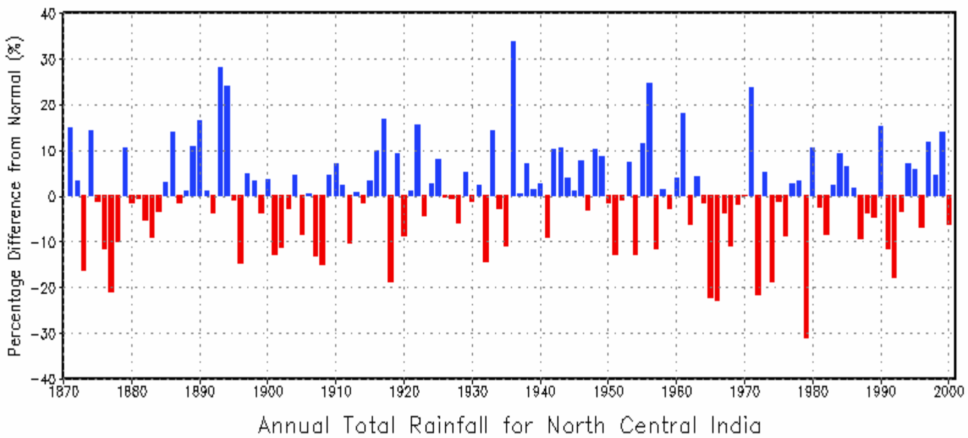

DAY 0
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
-20
-12
-4
4
12
20
-24
-16
-8
0
8
16
24

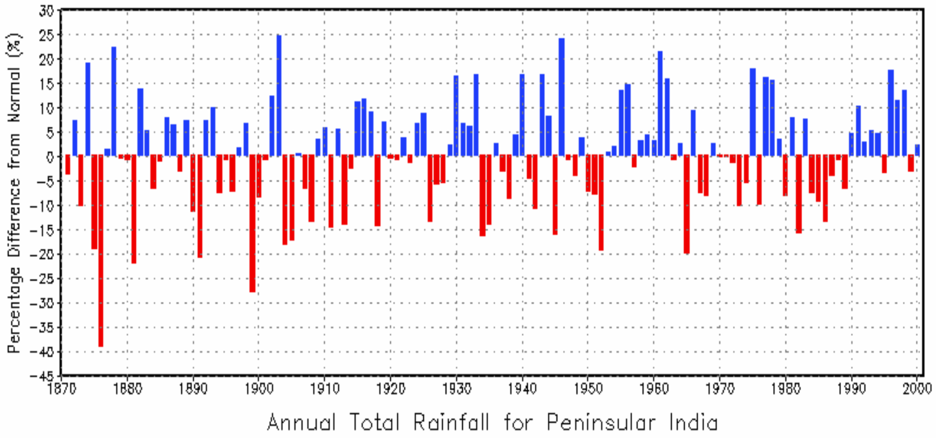


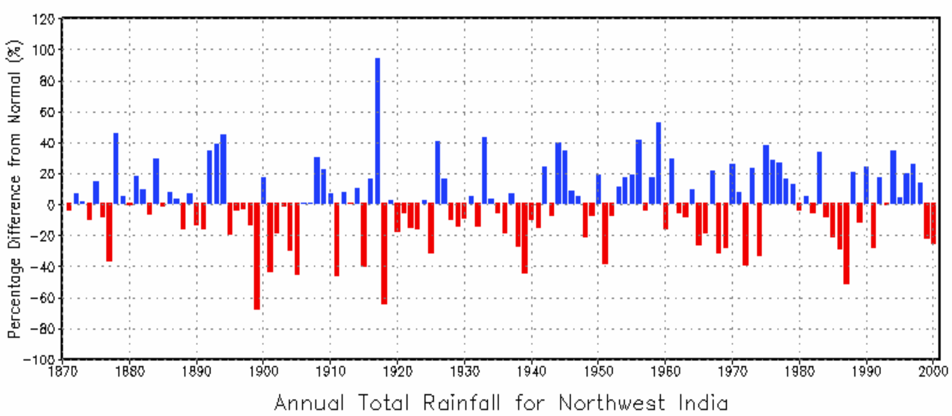
Annual Global Precipitation Anomalies
January - December, 1900 - 2001
Filtered Values
Wetter than Normal
Drier than Normal
Based on
1900-2000 mean
75.0
50.0
25.0
0.0
-25.0
-50.0
-75.0
mm
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
Inches
1900
1920
1940
1960
1980
2000
Year

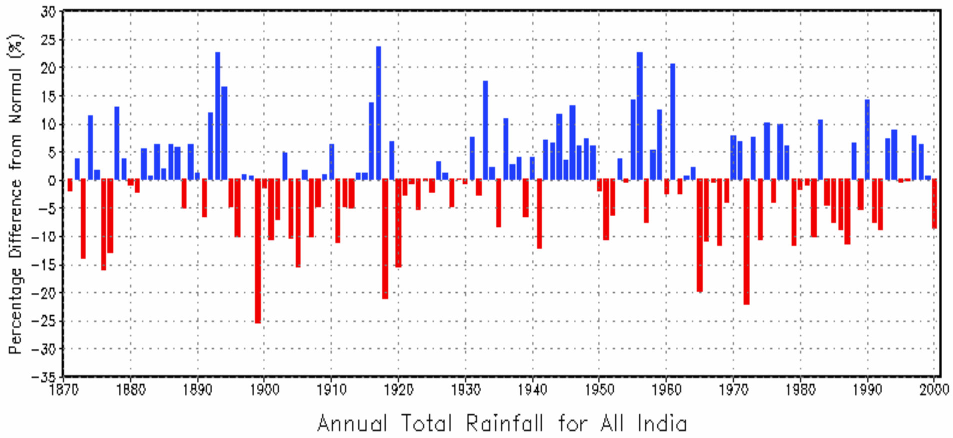
Observed Rainfall Variability in India









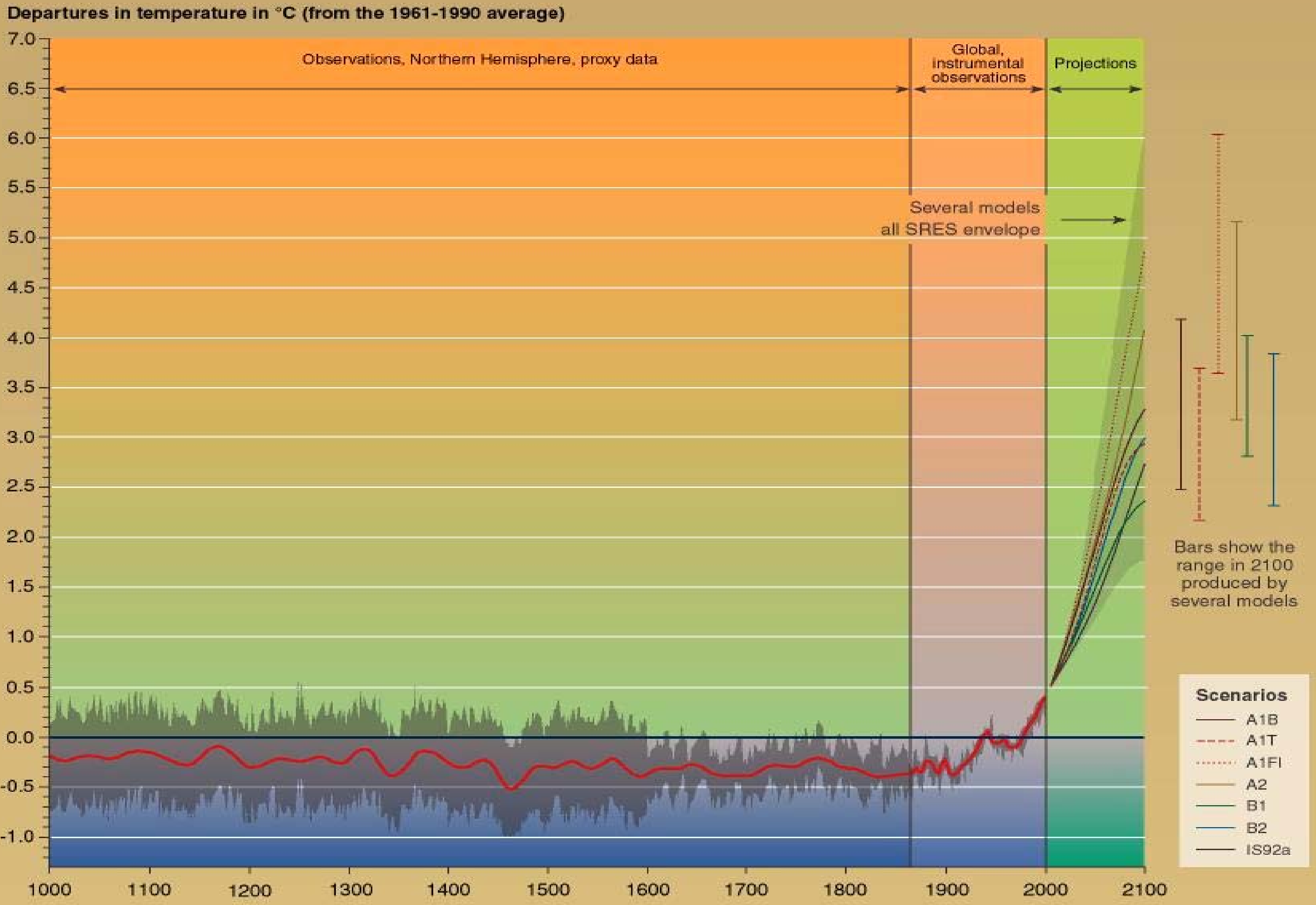


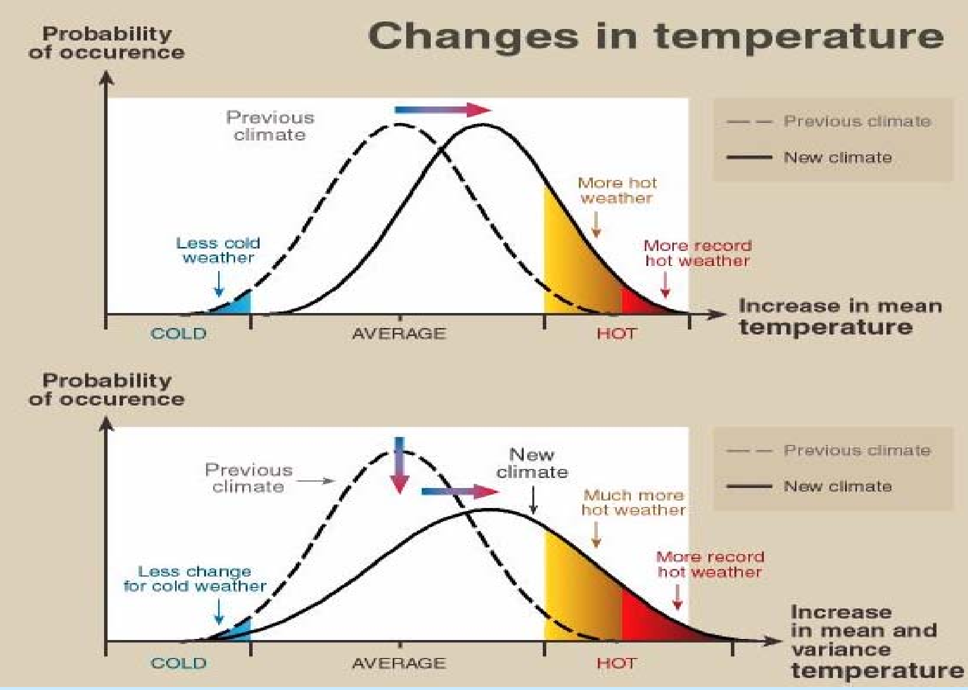
Droughts

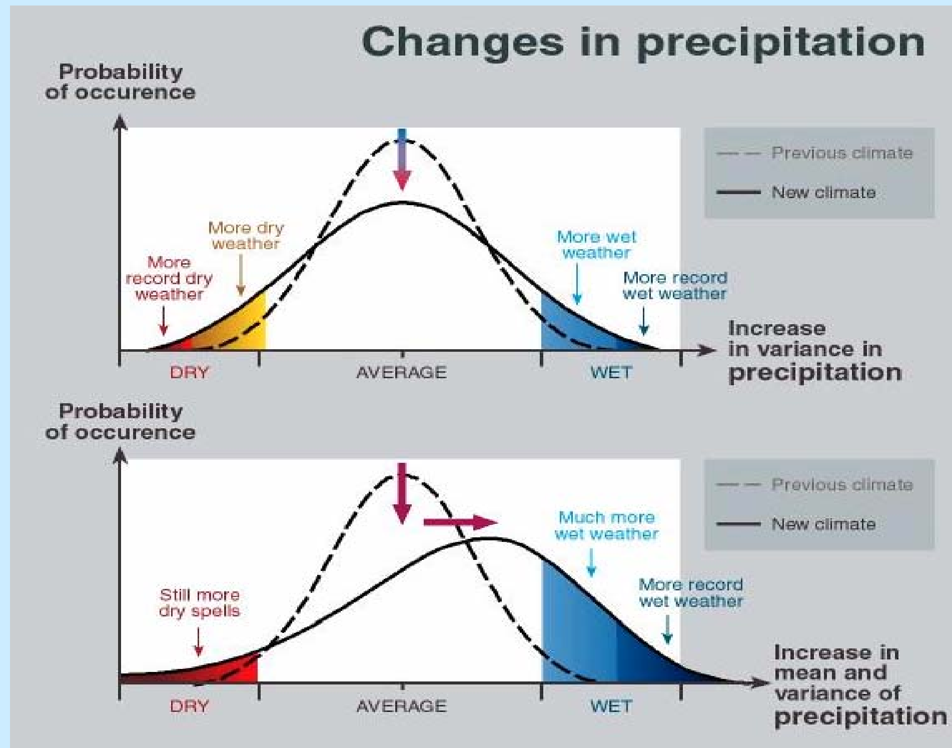
Floods

If the growth rate of atmospheric greenhouse gases accelerates in the future, the average global surface temperature is projected to **increase** by between **1.4**^{o} and 3^{o}C above 1990 levels **by 2100** for low emission scenarios and between 2.5^{o} and **5.8**^{o}C for higher emission scenarios.

Variations of the earth's surface temperature: 1000 to 2100



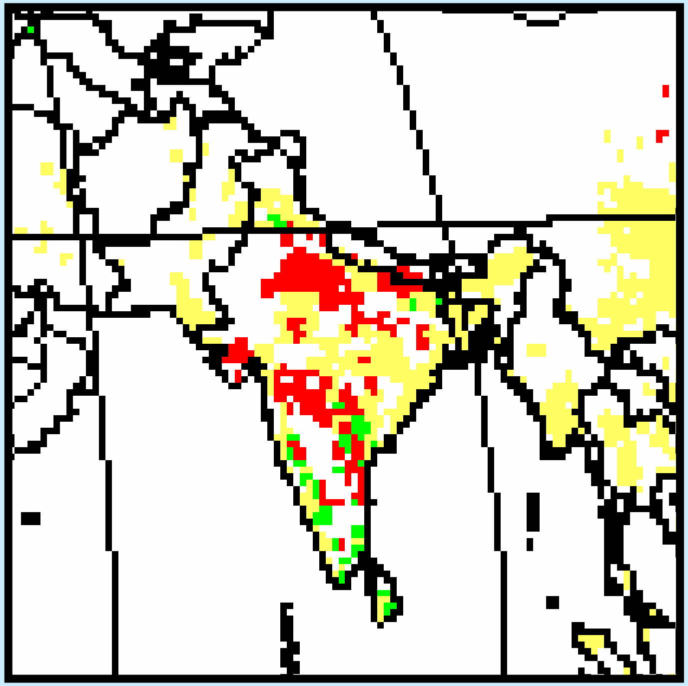

Changes in temperature
Probability of occurence
Previous climate
Less cold weather
More hot weather
More record hot weather
Previous climate
New climate
COLD
AVERAGE
HOT
Increase in mean temperature
Probability of occurence
Previous climate
New climate
Less change for cold weather
Much more hot weather
More record hot weather
Previous climate
New climate
COLD
AVERAGE
HOT
Increase in mean and variance temperature


Changes in precipitation
Probability of occurence
More record dry weather
More dry weather
More wet weather
More record wet weather
Previous climate
New climate
DRY
AVERAGE
WET
Increase in variance in precipitation
Probability of occurence
Still more dry spells
Much more wet weather
More record wet weather
Previous climate
New climate
DRY
AVERAGE
WET
Increase in mean and variance of precipitation

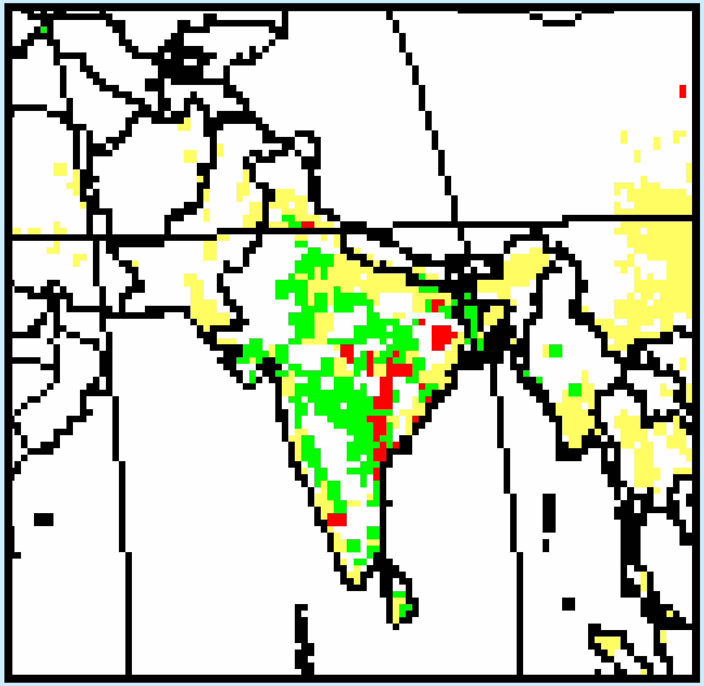
In order to assess the social and environmental impacts of climate change and to develop suitable policies to respond to such impacts, information about climate change is needed not only at a national level, but on a regional and local scale as well.

Obtaining reliable projections of climatic change at the regional scale is the central issue within the global change debate.

Regional Pattern of Changes in Maize Yield by 2080s



Hadley Centre, UK



M P I, Germany

Yield forecasts due to inter-model variance in climate projections

Reduced

No Change

Increased

Agriculture in S. Asia – Strengths & Challenges

Strong strides made in increasing the production in the past 50 years mainly due to adoption of HYVs and other technological developments in India and elsewhere,

Subsistence agriculture with small land holdings and skewed distribution of land,

Wide variation in regional productivities,

Majority still depend on rainfed agriculture,

Frequently affected by extreme weather events such as heat waves, droughts, floods and cyclones,

Significant proportion of population still reels under poverty, malnutrition and chronic hunger, and

Emerging economic challenges – WTO, economic liberalization etc.

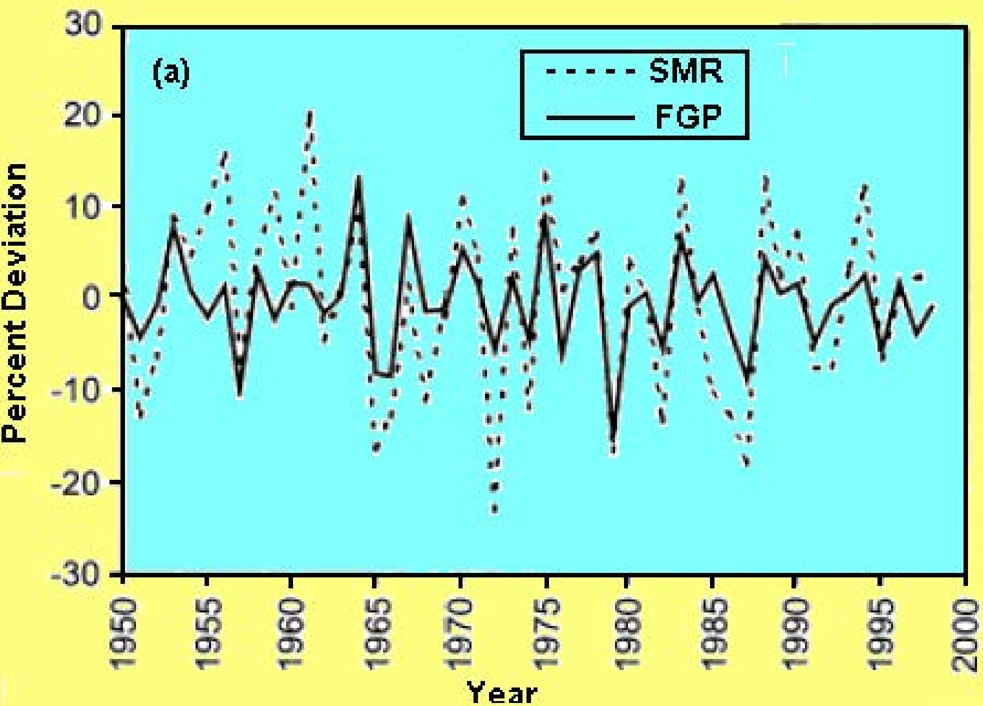
The fortunes of the agricultural sector in South Asia are heavily dependent on monsoon making it highly vulnerable to mercies of weather.

The agricultural sector contributes 25% to the economy and 65% to the employment in India; this sector is crucial to the economy of most other countries in the region as well.

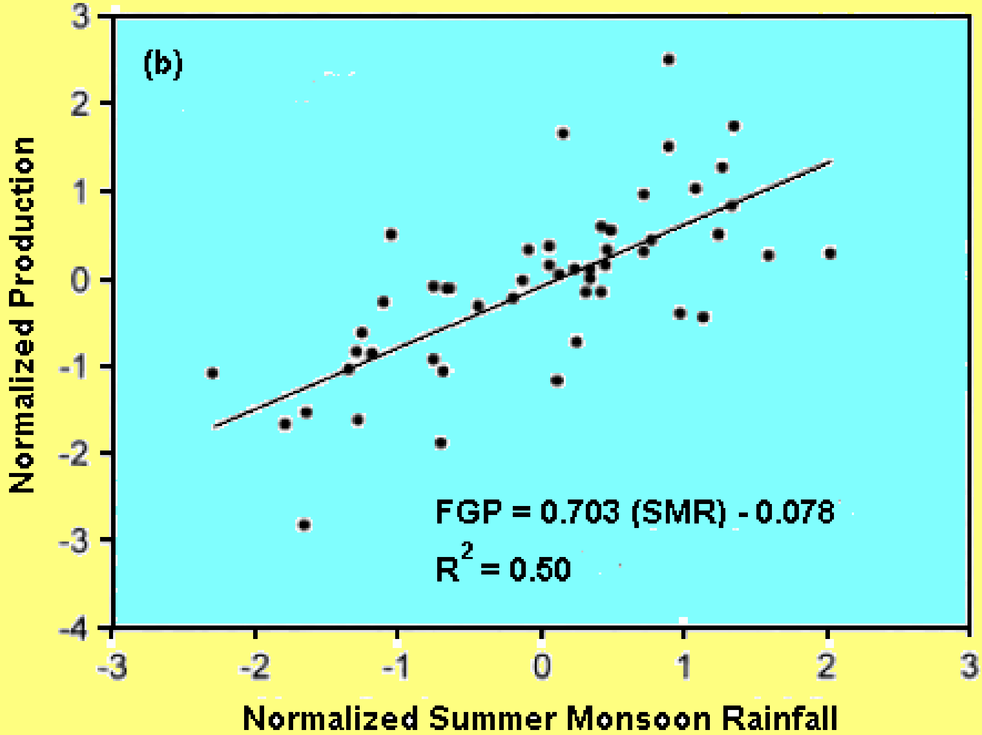
Agriculture remains Nepal's principal economic activity, employing 80% of the population and providing 37% of GDP even though only about 20% of the total area is cultivable.

In Pakistan, agriculture, and small-scale forestry and fishing, contributes 25% of GDP and employs 48% of the labor force.

The agriculture sector in Bangladesh also plays an important role in the national economy accounting for 31.6% of total GDP and 63.2% of total national employment.



Relationship between summer monsoon rainfall (SMR) and food grain production (FGP) in India: (a) percent deviation from normal, and (b) scatter between normalized SMR and FGP



Water Budget for key South Asian Countries

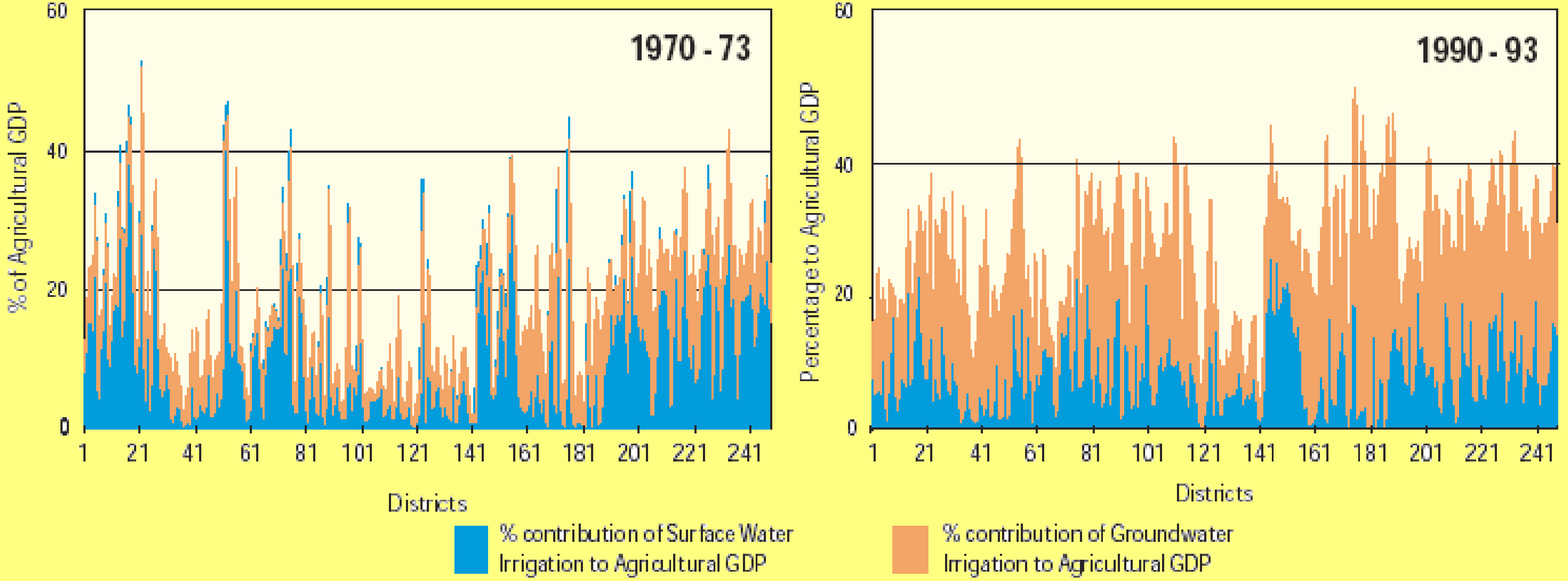
		India	Pakistan	Bangladesh	Nepal
Annual Internal Renewable (km3)		1850	298	1357	170
Annual Withdrawal (km3)		380	153.4	22.5	2.68
From outside the country borders		235	170	1000	0
Sectoral Withdrawal (%)	Domestic	3	2	3	4
	Industry	4	2	1	1
	Agriculture	93	97	96	96

Water consumed for food production (litres evapotranspired per kilogram)

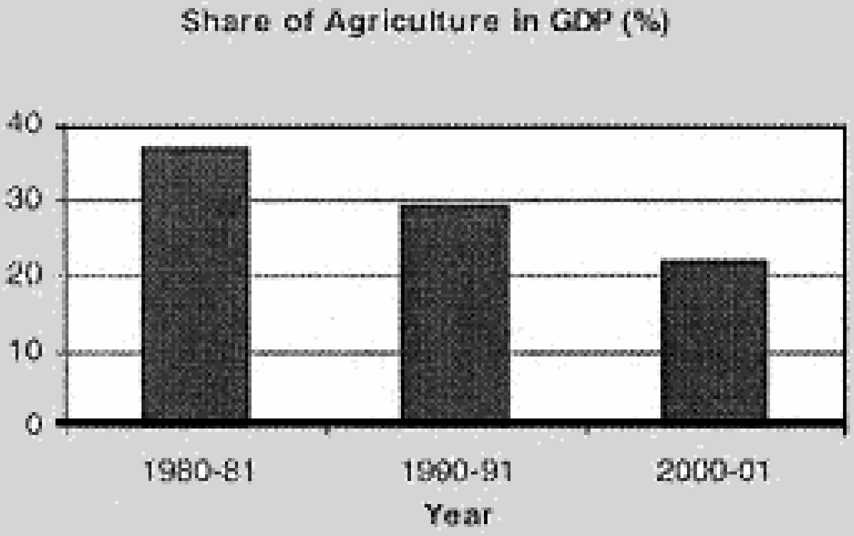
	USA	France	China	India	Japan	World
Wheat [a]	1,390	660	1,280	2,560	1,350	1,790
Rice [a]	1,920	1,270	1,370	3,700	1,350	2,380
Maize [a]	670	610	1,190	4,350		1,390
Beef [b]	10,060	7,740	12,600	14,379	9,540	9,680
Pork [b]	3,370	1,940	2,520	7,560	4,080	3,680

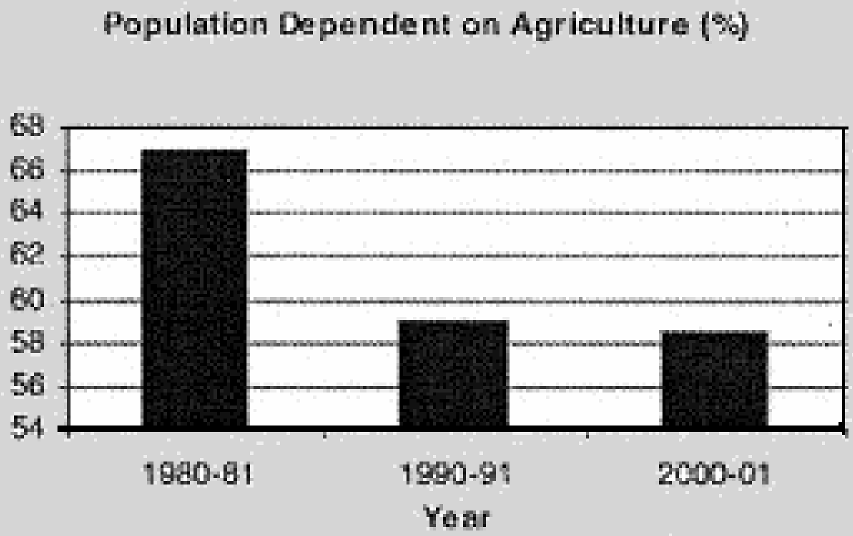
[a]from Fraiture et al (2004) [b]Chapagain and Hoekstra (2003)

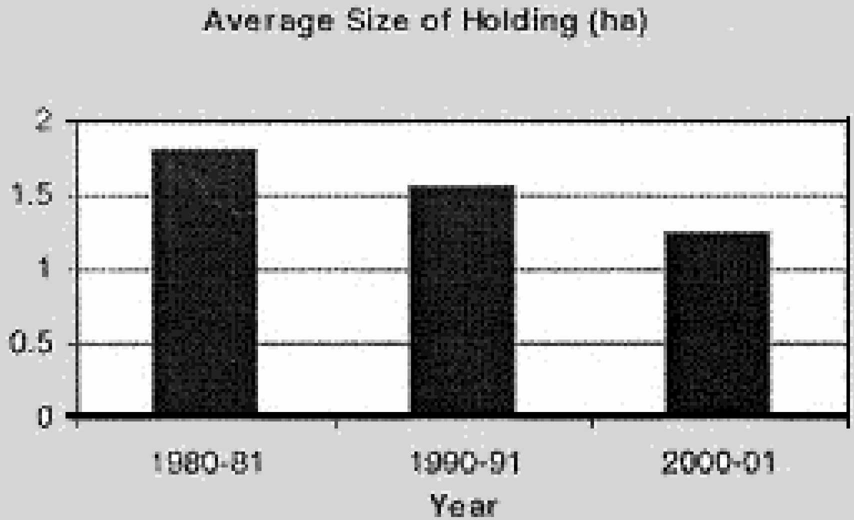
Change in contribution of groundwater and surface-water irrigation to agricultural GDP in India

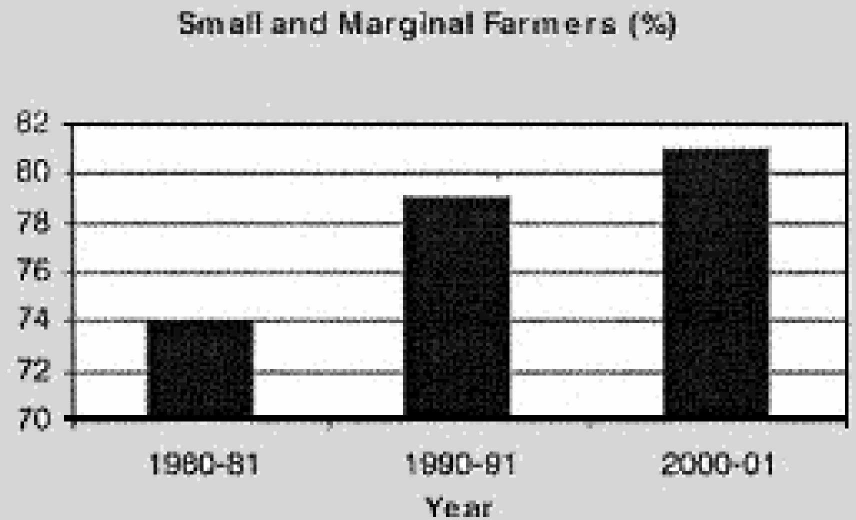


Status of Agriculture in India









Aggregate production increased by about 26 mt in the 1990s as against 52 mt in the 1980s.

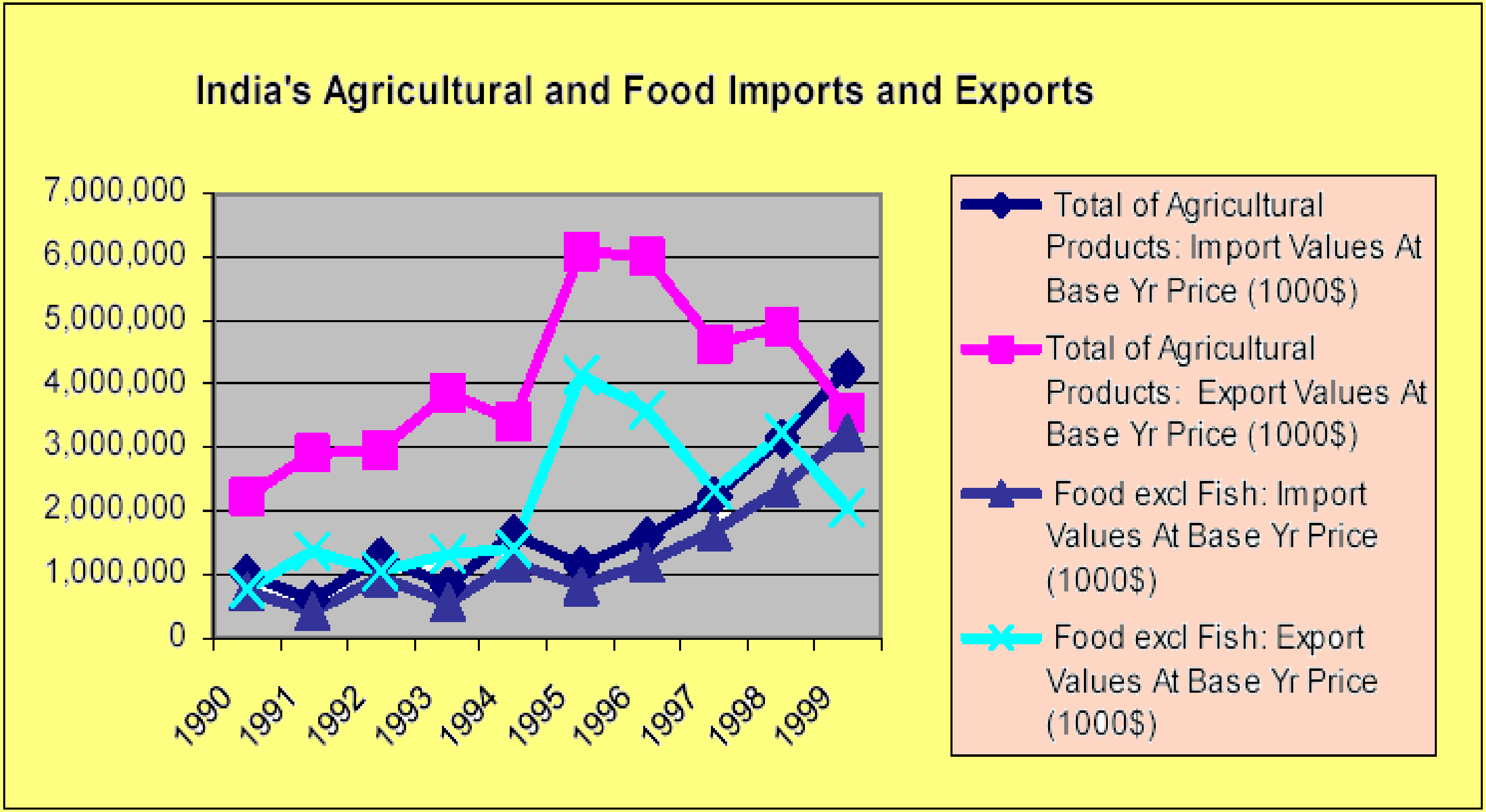
However, the growth rate of food grains production was markedly lower in the 1990s than in the 1980s.

The average yield rate of rice in India has grown at a compound rate of 1.1% annually in the 1990s against 3% annually in the 1980s.

The average yield rate of wheat has grown at a compound rate of 1.6% annually in the 1990s against 3% annually in the 1980s.

India's Current Food Production and Targets

	Production (Mt), 2000	Target Production (Mt),	
		2010	2020
Rice	85.4	103.6	122.1
Wheat	71.0	85.8	102.8
Coarse grains	29.9	34.9	40.9
Total Cereals	184.7	224.3	265.8
Pulses	16.1	16.1	27.8
Food Grains	200.8	245.7	293.6


India's Agricultural and Food Imports and Exports
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Total of Agricultural Products: Import Values At Base Yr Price (1000$)
Total of Agricultural Products: Export Values At Base Yr Price (1000$)
Food excl Fish: Import Values At Base Yr Price (1000$)
Food excl Fish: Export Values At Base Yr Price (1000$)

Per capita availability of food grains in India has increased in the 1990s: up by 12 grams a day from 472 grams per day in 1990 to 485 grams per day in 2000.

But the <u>deceleration in food grains production</u> in the 1990s creates the spectre of food shortage in the years ahead.

India:

15% of world population

4% of world's water resources

Utilizable Surface water: 690 BCM/yr

Replenishible Ground Water: 432 BCM/yr

Total : 1132 BCM / year

Per Capita Annual Water Availability in cu.m/year in India

The Past & The Present:

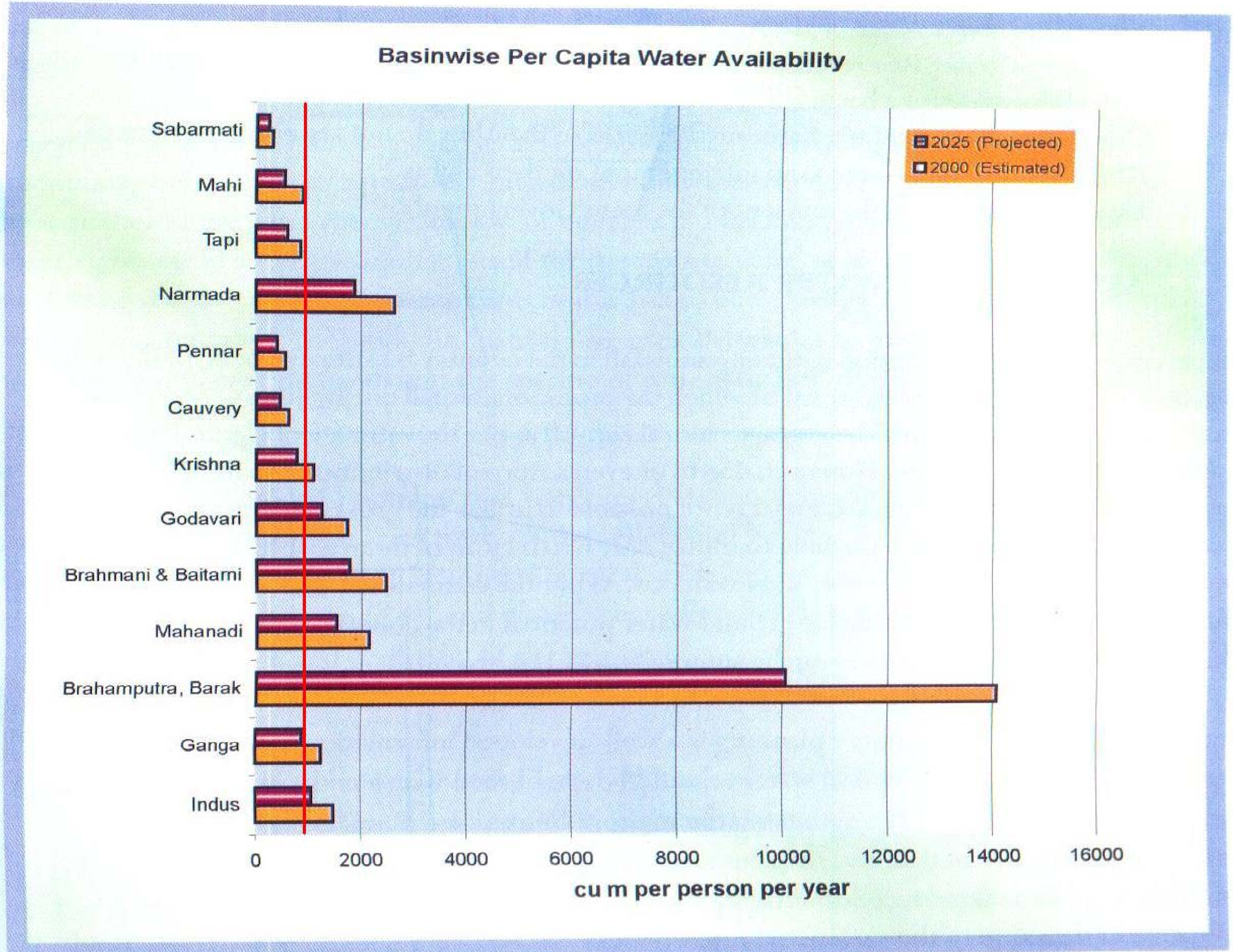
1951 – 5177; 2001 – 1820

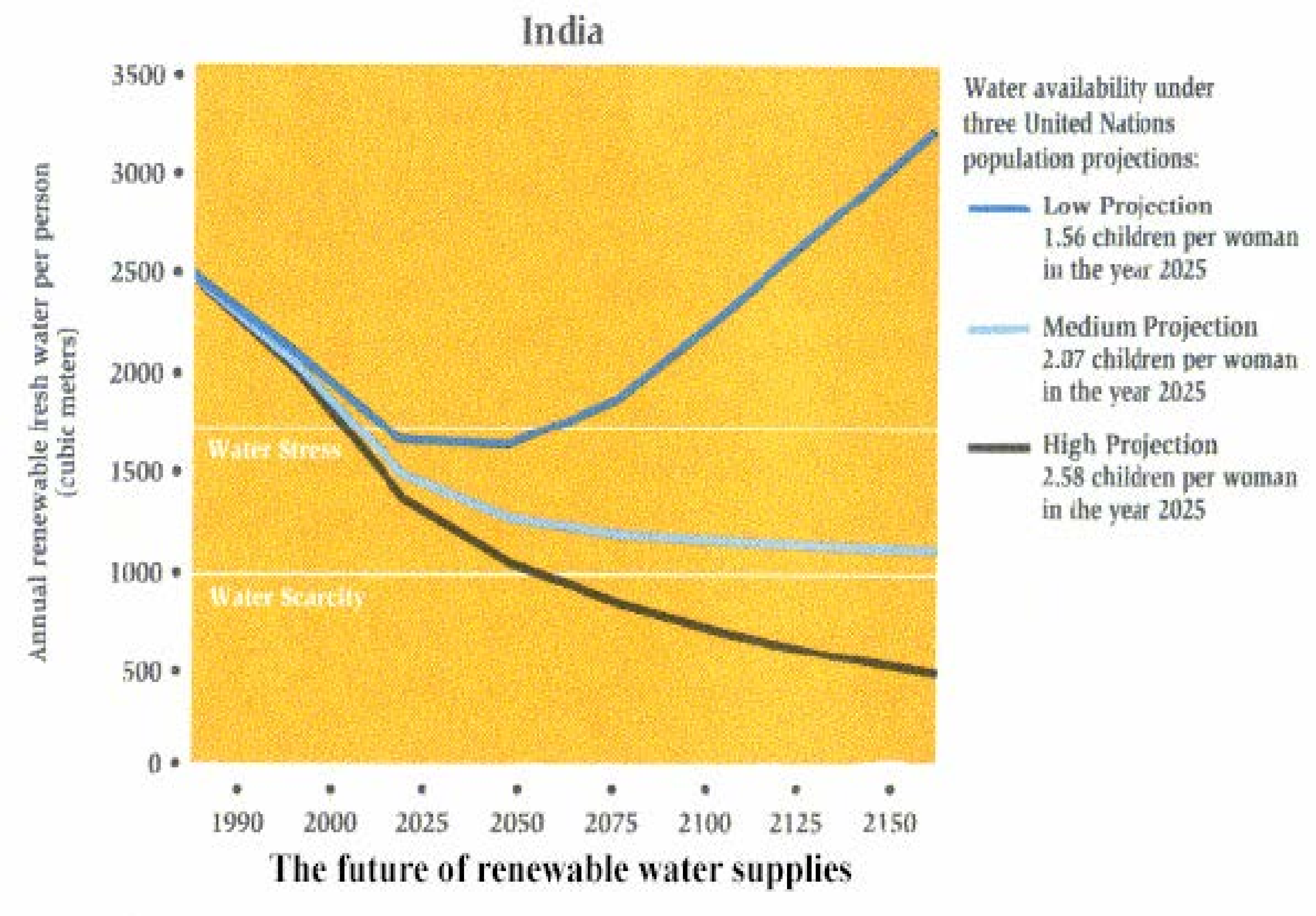
Future Projections:

2025 : 1341; 2050 : 1140

In Pakistan:

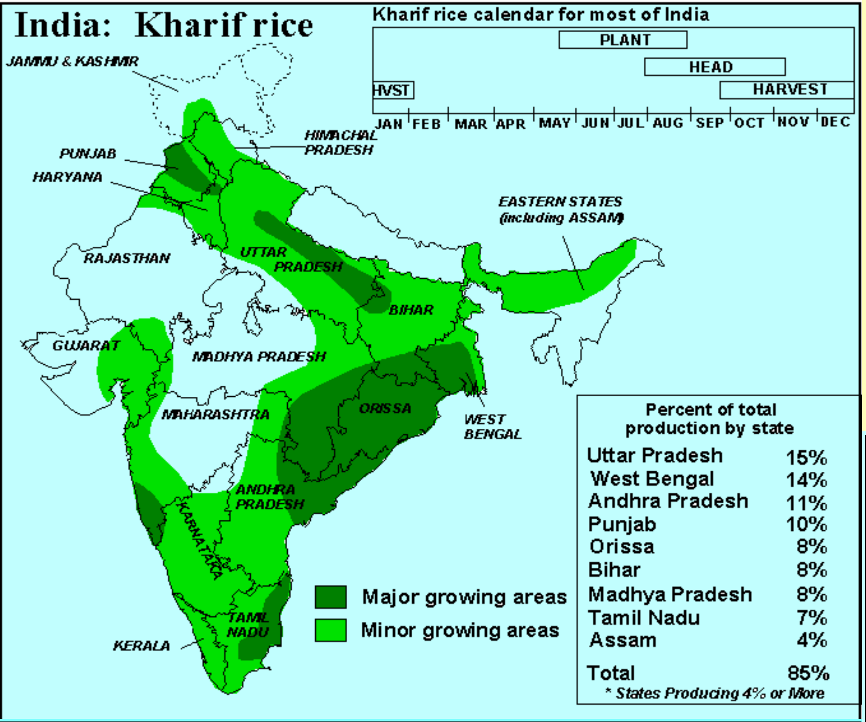
5650 m^3 in 1951, 1000 m^3 in 2001-02


Basinwise Per Capita Water Availability
Sabarmati
Mahi
Tapi
Narmada
Pennar
Cauvery
Krishna
Godavari
Brahmani & Baitarni
Mahanadi
Brahamputra, Barak
Ganga
Indus
2025 (Projected)
2000 (Estimated)
0
2000
4000
6000
8000
10000
12000
14000
16000
cu m per person per year


India
Annual renewable fresh water per person (cubic meters)
3500
3000
2500
2000
1500
1000
500
0
Water Stress
Water Scarcity
1990
2000
2025
2050
2075
2100
2125
2150
The future of renewable water supplies
Water availability under three United Nations population projections:
Low Projection 1.56 children per woman in the year 2025
Medium Projection 2.07 children per woman in the year 2025
High Projection 2.58 children per woman in the year 2025

With the introduction of new, improved shorter duration wheat and rice varieties in South Asia in the mid-1960s, double cropping of these two cereals became possible. Rice is grown in the wet, monsoon summer months and wheat follows in the dry, cool winter in one calendar year. More than 12 million ha are grown to rice and wheat in Bangladesh, India, Nepal, and Pakistan. Another 10 million ha are grown in China. This rice-wheat system is one of the most important cropping systems for cereal production and food security in the region.

India: Kharif rice

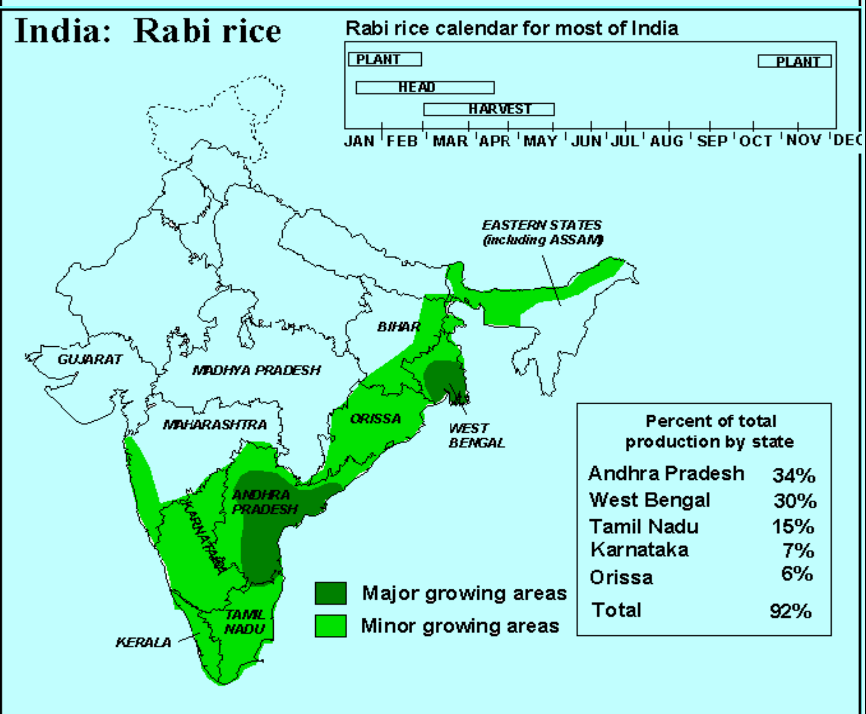


Percent of total production by state

Uttar Pradesh	15%
West Bengal	14%
Andhra Pradesh	11%
Punjab	10%
Orissa	8%
Bihar	8%
Madhya Pradesh	8%
Tamil Nadu	7%
Assam	4%
Total	85%

* States Producing 4% or More

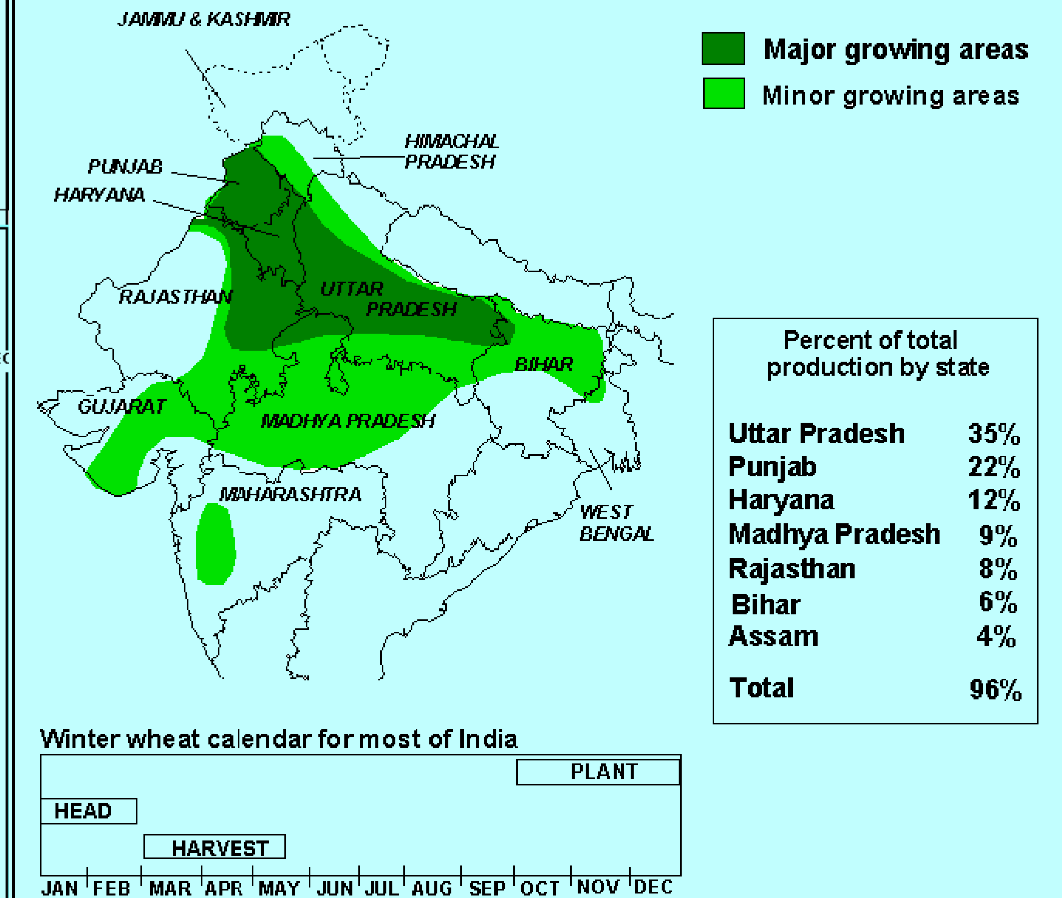
India: Rabi rice



Percent of total production by state

Andhra Pradesh	34%
West Bengal	30%
Tamil Nadu	15%
Karnataka	7%
Orissa	6%
Total	92%

India: Winter wheat



Percent of total production by state

Uttar Pradesh	35%
Punjab	22%
Haryana	12%
Madhya Pradesh	9%
Rajasthan	8%
Bihar	6%
Assam	4%
Total	96%

Supply and demand projections of rice and wheat crops ('000 tons) for South Asia to 2020

Country	Crop	Projections for 2020	
		Supply	Demand
Bangladesh	Rice	26270	27070
	Wheat	2185	4885
India	Rice	120100	120976
	Wheat	94780	100595
Pakistan	Rice	6524	4826
	Wheat	25963	33517
South Asia**	Rice	157940	158710
	Wheat	127370	147060

** Includes Bangladesh, India, Pakistan, Nepal, Afghanistan, Maldives and Sri Lanka

From Food Security point of view, wheat and rice are two most important staple food in South Asia.

In the 21st century, South Asian countries have to produce more food and other agricultural commodities under conditions of diminishing per capita arable land and irrigation water resources and expanding biotic as well as abiotic stresses including the climatic constraints.

Increased productivity and sustained production of food grains and legumes, industrial crops (oil, gum and resins, beverage, fibre, medicines, aromatic plants) and horticultural crops through crop diversification is critical for food and nutritional security in the South Asia.

The water demand in most countries of South Asia is gradually increasing because of increases in population, irrigated agriculture and growth in the industrial sectors.

Globally averaged rainfall is projected to increase, but at the regional scale both increases and decreases are likely.

Changes in water supply and demand caused by climate change will be overlaid on top of changing water use.

The rising surface air temperatures and carbon dioxide and enhanced variability in rainfall associated with global warming could have serious direct and indirect consequences on crop production.

Agricultural productivity is projected to decline in most tropical countries due to thermal and water stresses.

Climate variability will continue to affect strategic grain supplies and food security of many nations in South Asia.

The UNFCCC sets an "ultimate objective" of stabilizing "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system."

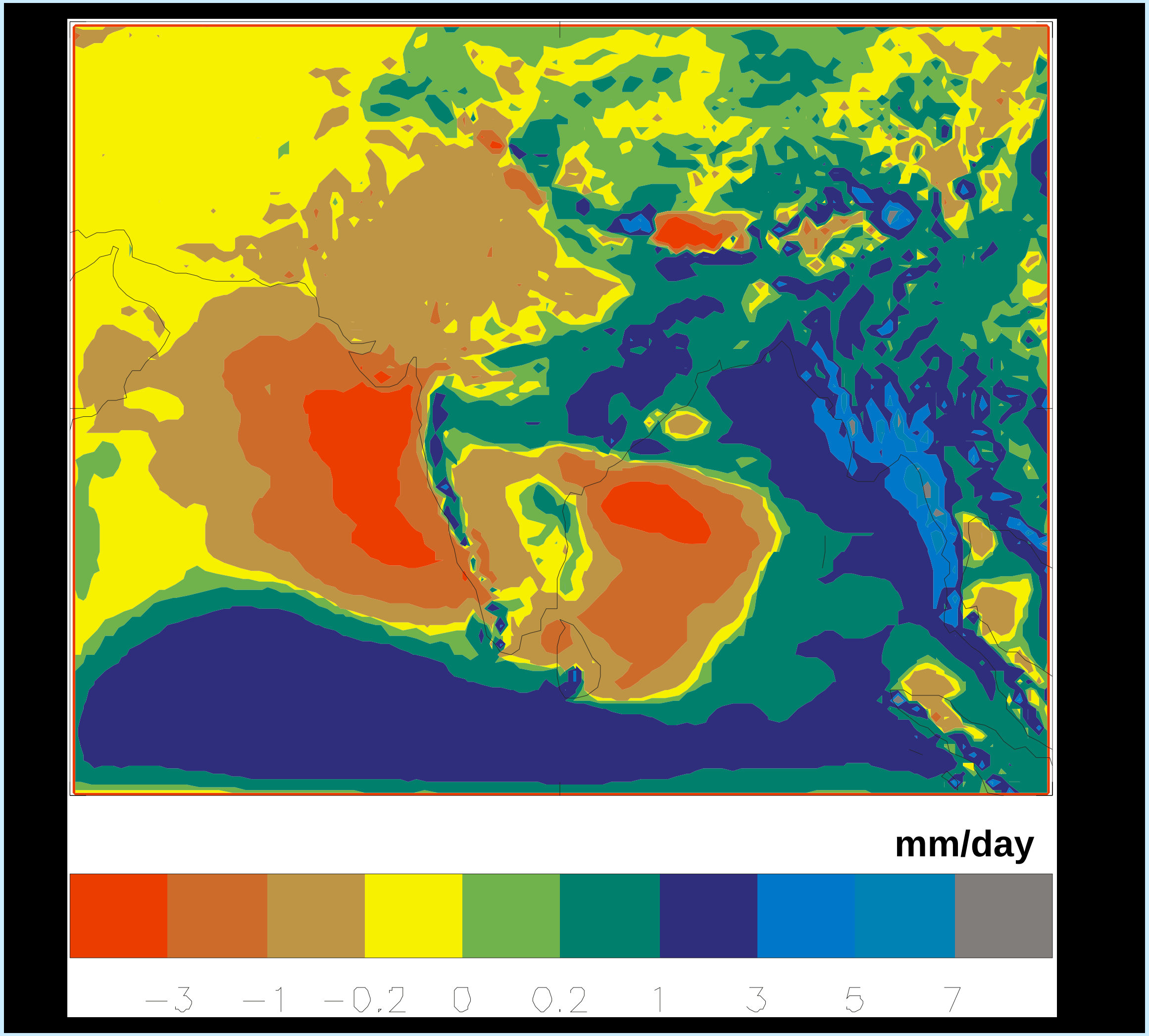
It directs that "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Projected changes (relative to 1961-1990 mean) in surface air temperature and precipitation in South Asia under SRES A1FI (highest future emission trajectory) and B1 (lowest future emission trajectory) pathways for three time slices, namely 2020s, 2050s and 2080s.

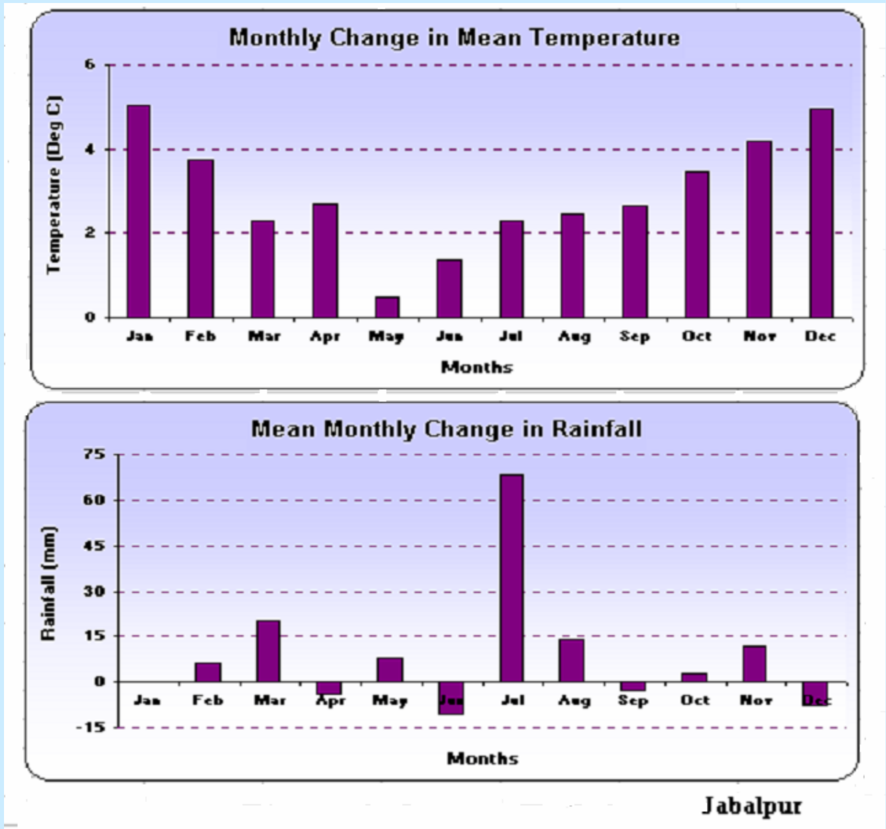
Region	Season	2010-2039				2040-2069				2070-2099			
		Temperature, deg C		Precipitation, %		Temperature, deg C		Precipitation, %		Temperature, deg C		Precipitation, %	
		A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1
South Asia	DJF	1.17	1.11	-3	4	3.16	1.97	0	0	5.44	2.93	-16	-6
	MAM	1.18	1.07	7	8	2.97	1.81	26	24	5.22	2.71	31	20
	JJA	0.54	0.55	5	7	1.71	0.88	13	11	3.14	1.56	26	15
	SON	0.78	0.83	1	3	2.41	1.49	8	6	4.19	2.17	26	10
	Annual	0.94	0.90	3	5	2.71	1.73	9	7	4.67	2.62	15	9

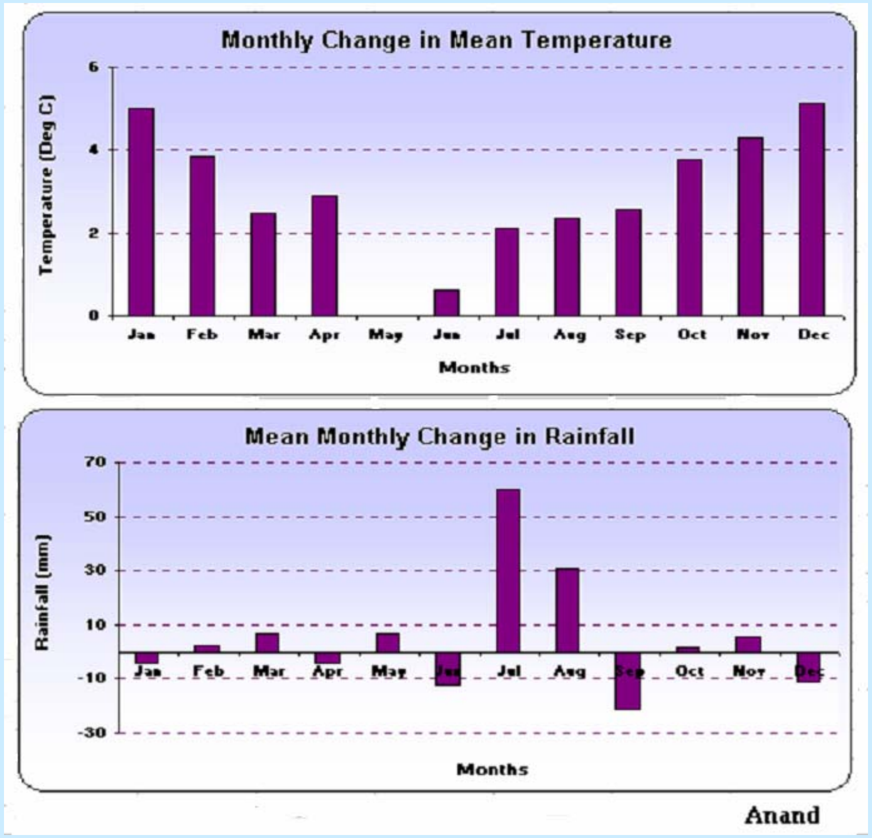
RAINFALL CHANGE OVER SOUTH ASIA

as simulated by Regional Climate Model

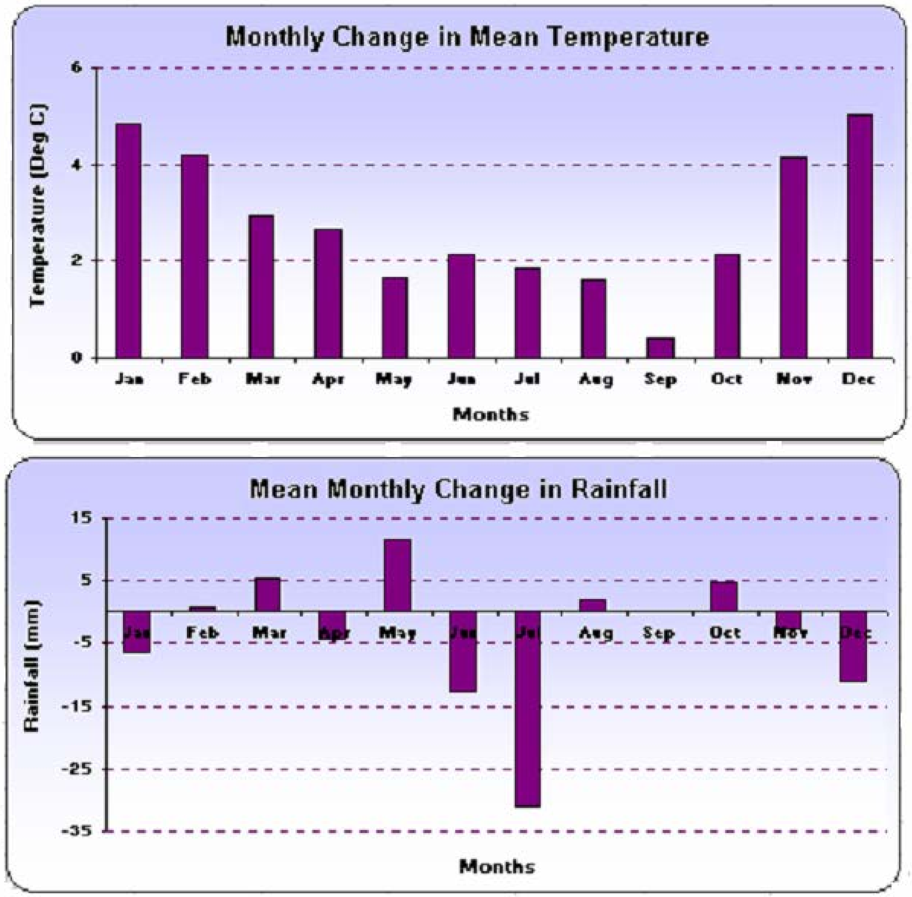


Simulation of Monthly Mean Changes in Surface Air Temperature and Rainfall

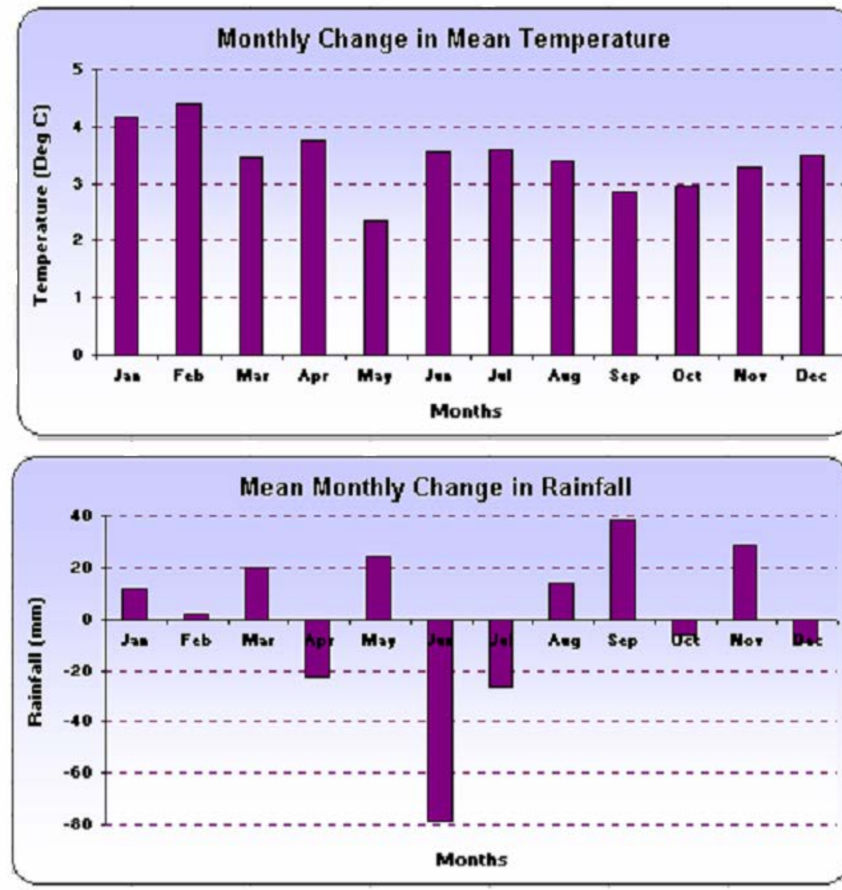




Simulation of Monthly Mean Changes in Surface Air Temperature and Rainfall

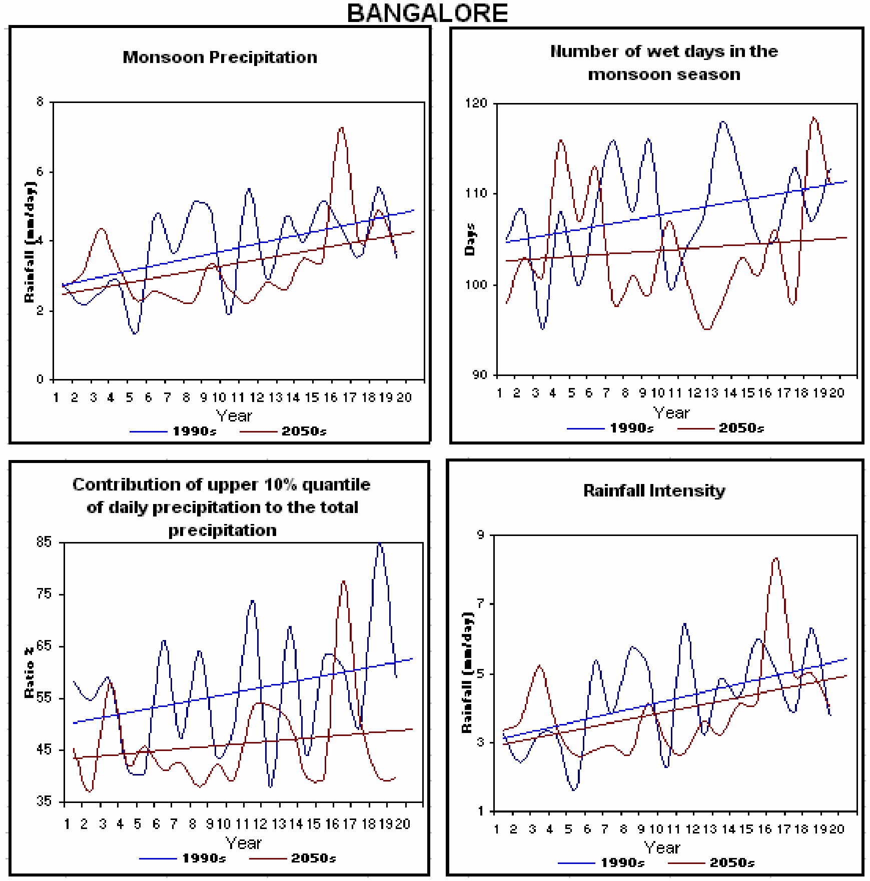


Ludhiana

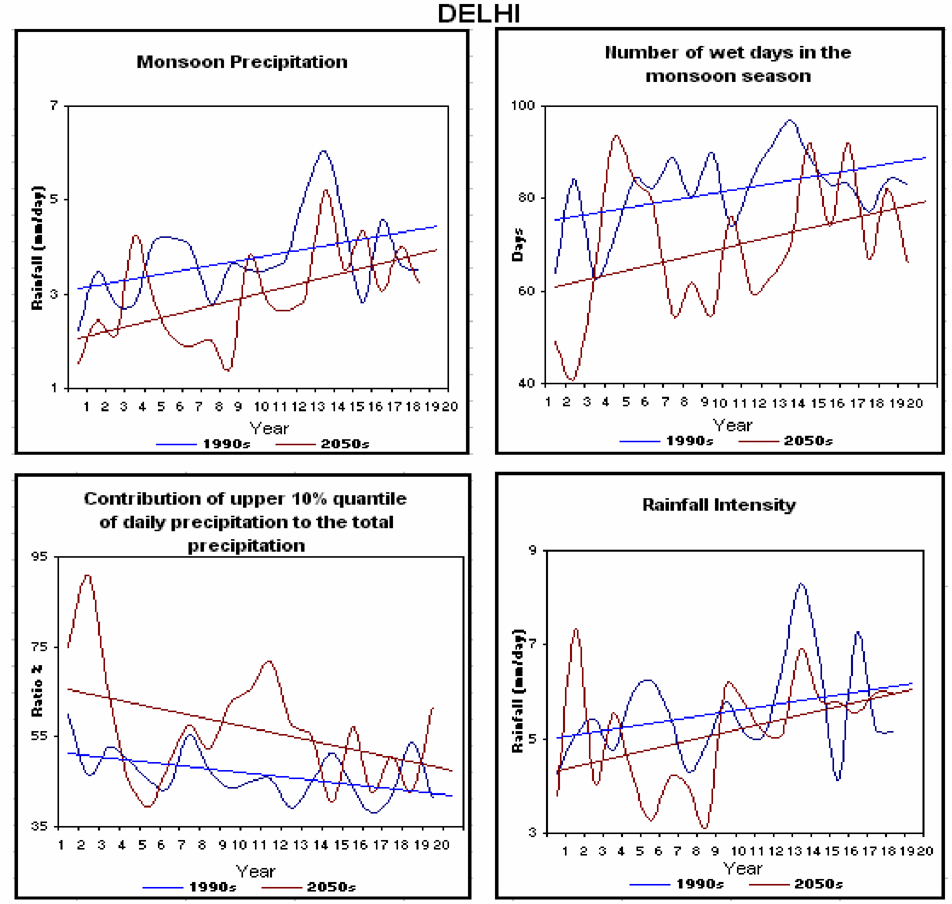


Bangalore

Simulation of Extreme rainfall Events and Intra-Seasonal Variability in Monsoon Rainfall

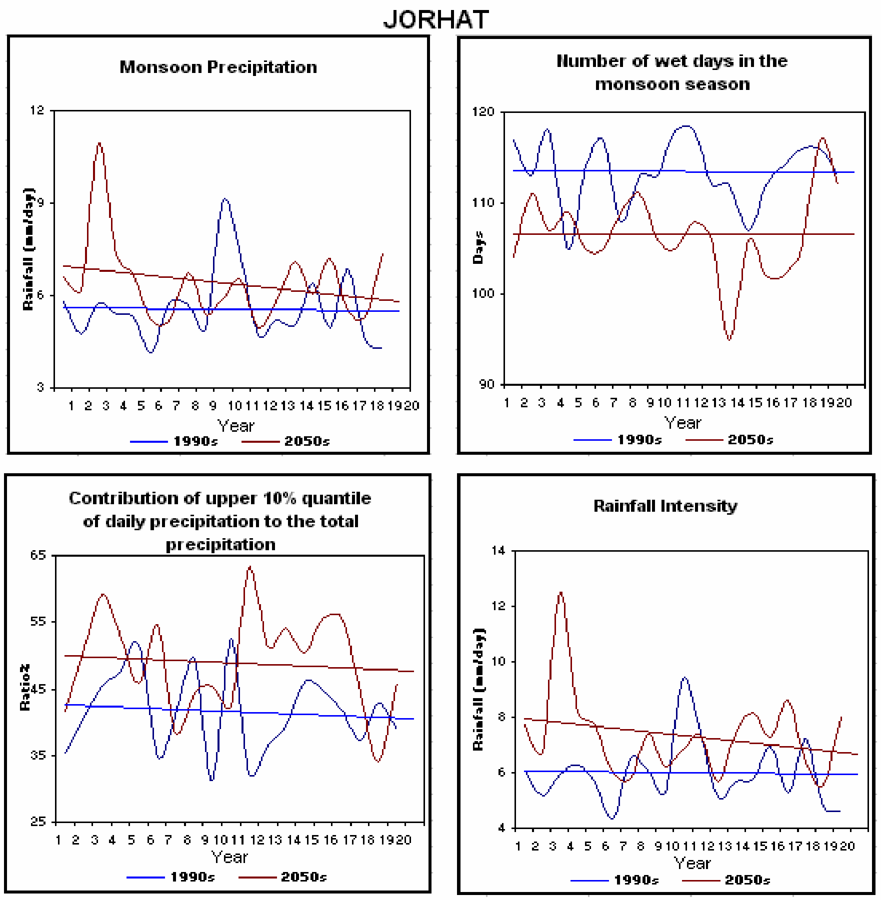


Key characteristics of summer monsoon rainfall over Bangalore as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

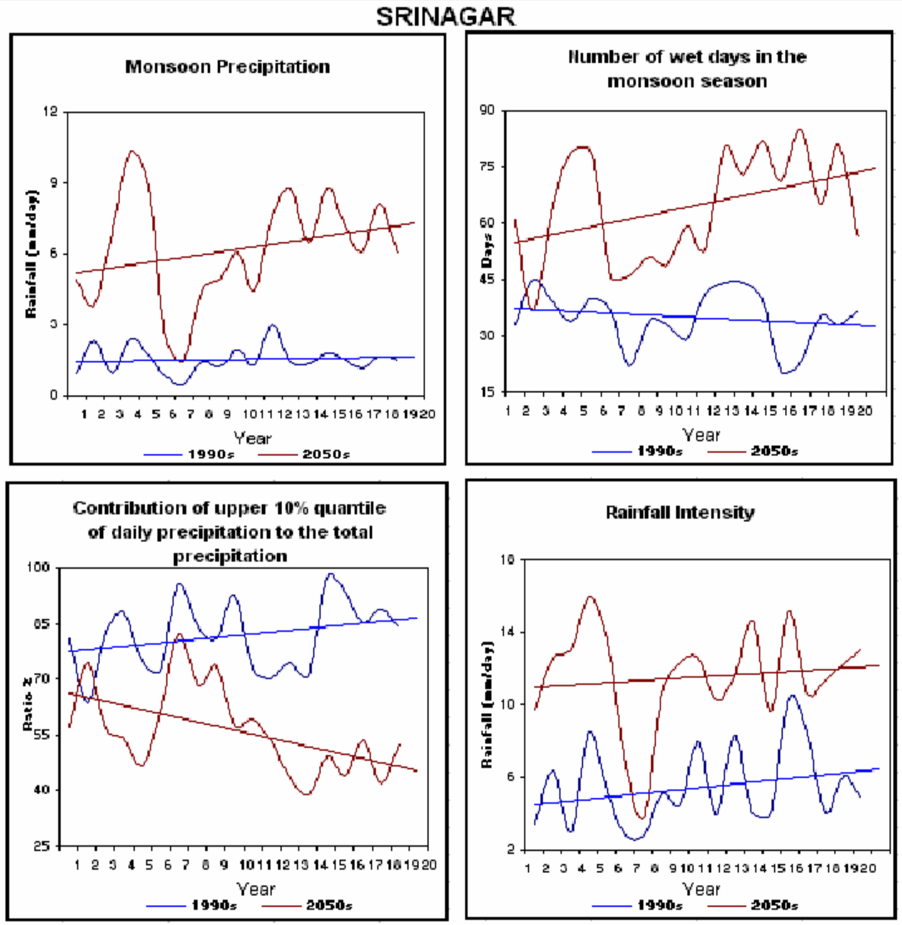


Key characteristics of summer monsoon rainfall over Delhi as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

Simulation of Extreme rainfall Events and Intra-Seasonal Variability in Monsoon Rainfall

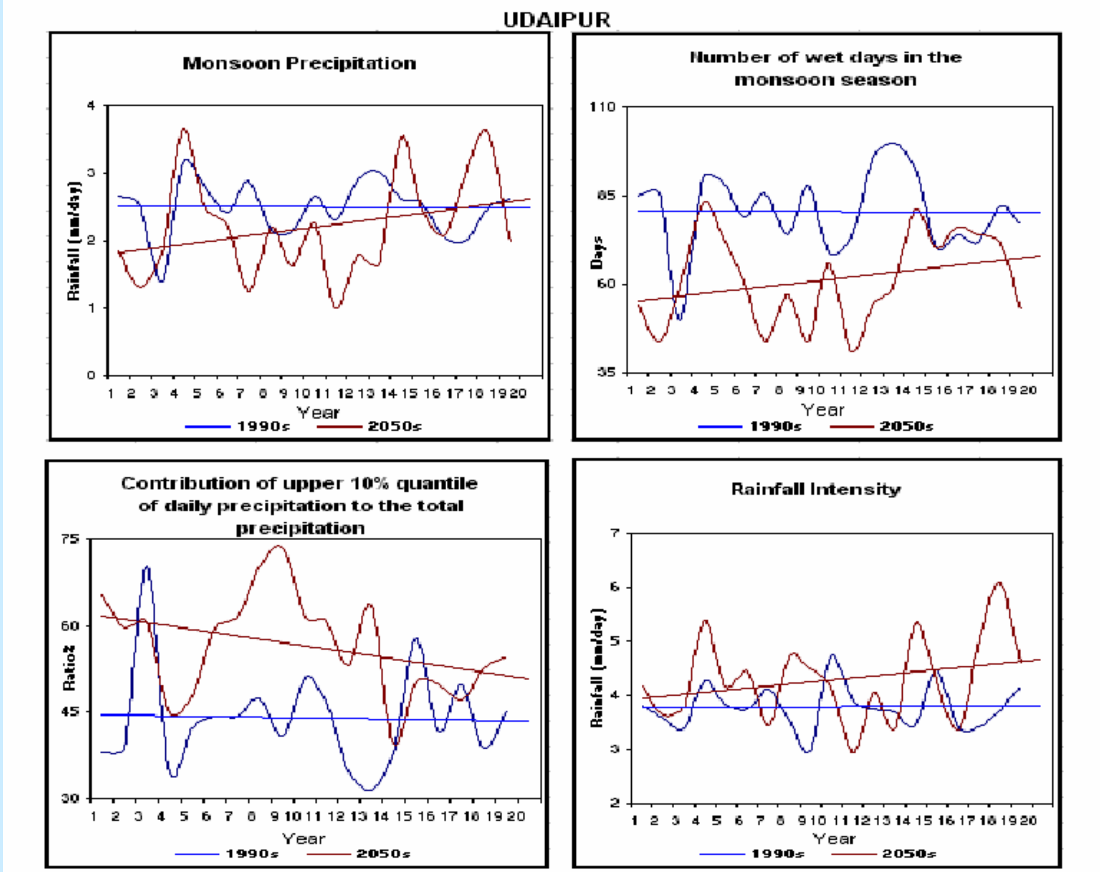


Key characteristics of summer monsoon rainfall over Jorhat as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings



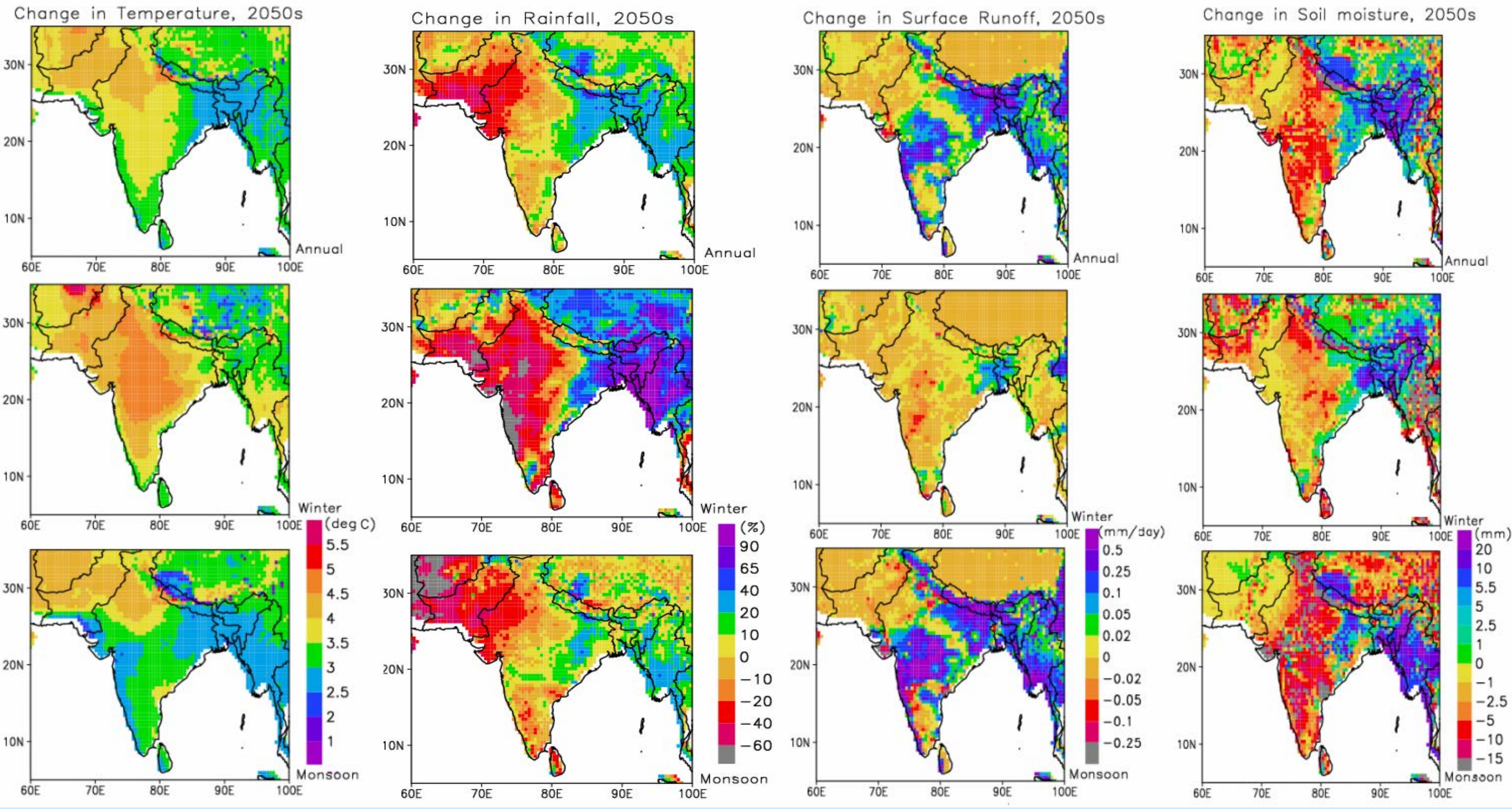
Key characteristics of summer monsoon rainfall over Srinagar as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

Simulation of Extreme rainfall Events and Intra-Seasonal Variability in Monsoon Rainfall



Key characteristics of summer monsoon rainfall over Udaipur as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

Spatial Distribution of Projected Seasonal Changes in Surface Air Temperature, Rainfall, Surface Runoff and Soil Moisture



In view of the fact that the water and agriculture sectors are likely to be most sensitive to climate change induced impact in South Asia, these climate projections have been adapted to simulate potential crop yields through application of crop simulation models and hence to obtain the range of possible impacts of likely changes in mean and variance in key climate variables (maximum and minimum surface air temperatures, solar radiation and rainfall) in the year 2050 with respect to present-day conditions (daily weather data used for 1961 to 1990 and 2035 to 2064) on the productivity of rainfed wheat and rice (the two most important staple food crops in South Asia).

Percent Change in Cereal Crop Yields in South Asia				
Scenarios	Rainfed Rice		Rainfed Wheat	
	N. South Asia	S. South Asia	N. South Asia	S. South Asia
2 X CO_2	+15%	+18%	+26%	+24%
2 X CO_2; +1°C	+4%	+6%	+21%	+22%
2 X CO_2; +2°C	-1%	-1%	+11%	+7%
2 X CO_2; +3°C	-12%	-8%	+2%	-1%
2 X CO_2; +2°C; +10%	+2%	+3%	+16%	+9%
2 X CO_2; +2°C; -10%	-5%	-4%	-3%	-8%
2 X CO_2; +2°C; -20%	-24%	-21%	-11%	-19%
2 X CO_2; +2°C; -20%; Proj. Climate Variability	-31%	-30%	-18%	-23%

N.South Asia (includes, Pakistan, North India, Nepal, Bangladesh)

S.South Asia (includes, South India, Sri Lanka)

A 2^{o}C increase in surface air temperature would decrease wheat yields in most of South Asian countries. The average change in wheat yields in South Asia would range between +4 to -34% for the mid-21st century under projected climate scenarios.

The yields in non-irrigated (rainfed) wheat and rice will significantly decline in South Asia for an increase of between 2.5 to 3.5^{o}C above the present-day surface air temperatures incurring a loss in farm level net revenue of between 9% and 25%.

An enhanced intra-seasonal and inter-annual variability of rainfall would also substantially affect the average output of rainfed agriculture in monsoon region of South Asia.

In long term (2050 and beyond), productivity of *kharif* (summer monsoon season) crops would decline due to increased climate variability and pest incidence and virulence.

Production of *Rabi* (winter season) crops is likely to be more seriously threatened in response to 2^{o}C warming with respect to the present-day surface air temperatures.

The net cereal production in South Asia is expected to decline at least between 4 to 10% by the end of this century under the most conservative climate change projections.

Overall crop productivity in central and south India, Bangladesh and Sri Lanka would be more adversely affected than in north India, Pakistan and Nepal.

In terms of the reference to UNFCCC Article 2 on dangerous anthropogenic interference with the climate system, the critical threshold for sustained food productivity in South Asia appears to be a rise of ~2^{o}C in surface air temperature with respect to present day (beyond the 2.5^{o}C warming above the pre-industrial level i.e., marginally above the EU Target of 2^{o}C rise in global mean temperature) and a 20% decline in summer monsoon rainfall.

The study further suggests that, alterations in the patterns of extreme events, such as increased frequency and intensity of droughts (prolonged dry spells), will have more serious consequences for chronic and transitory food insecurity than will shifts in the patterns of average temperature and rainfall.

On an aggregate level, there might not be a significant impact of global warming on food production of South Asia in the short term (<2^{o}C above the present-day surface air temperature; until about 2025) provided water for irrigation is available and agricultural pests could be kept under control (with improvement in management practices).

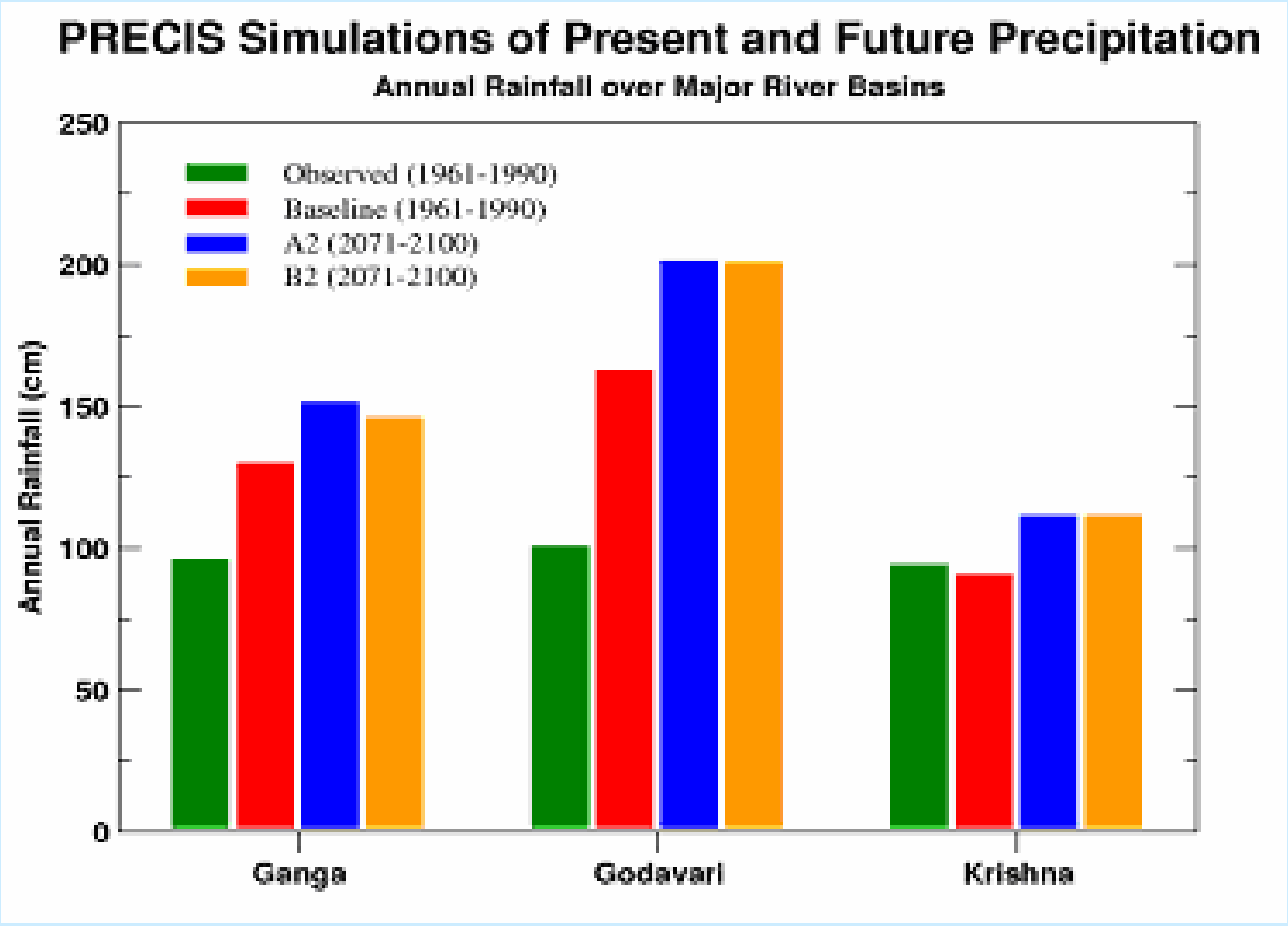
The increasing frequency of droughts and floods would, however, continue to seriously disrupt food supplies on year to year basis.

Critical areas for intervention would be:-

(i) Improving availability of seed/planting material of high yielding varieties,
(ii) Developing and promoting use of hybrids, especially for rainfed agro-ecosystems,
(iii) Expansion of areas under different crops and commodities through diversification of agriculture,
(iv) Improving productivity of crops, existing plantations and livestock,
(v) Developing infrastructure for post-harvest management, marketing and agribusiness,
(vi) Small farm mechanism, and
(vii) Transfer of technological inputs through assessments and refinements at regular time intervals in consonance with our understanding of climate variability and climate change.

Ensuring food security may remain an unaccomplished dream for many South Asian countries unless <u>appropriate adaptation and mitigation strategies are put in place</u> to ensure environmental and ecological protection and conservation of natural resources.

Thanks


PRECIS Simulations of Present and Future Precipitation
Annual Rainfall over Major River Basins
Observed (1961-1990)
Baseline (1961-1990)
A2 (2071-2100)
B2 (2071-2100)
Annual Rainfall (cm)
250
200
150
100
50
0
Ganga
Godavari
Krishna