Evidence for Weakening of Indian Summer Monsoon and SA CORDEX Results from RegCM

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Based on a paper entitled "Projected Seasonal Mean Summer Monsoon over India and Adjoining Regions for the 21st Century"

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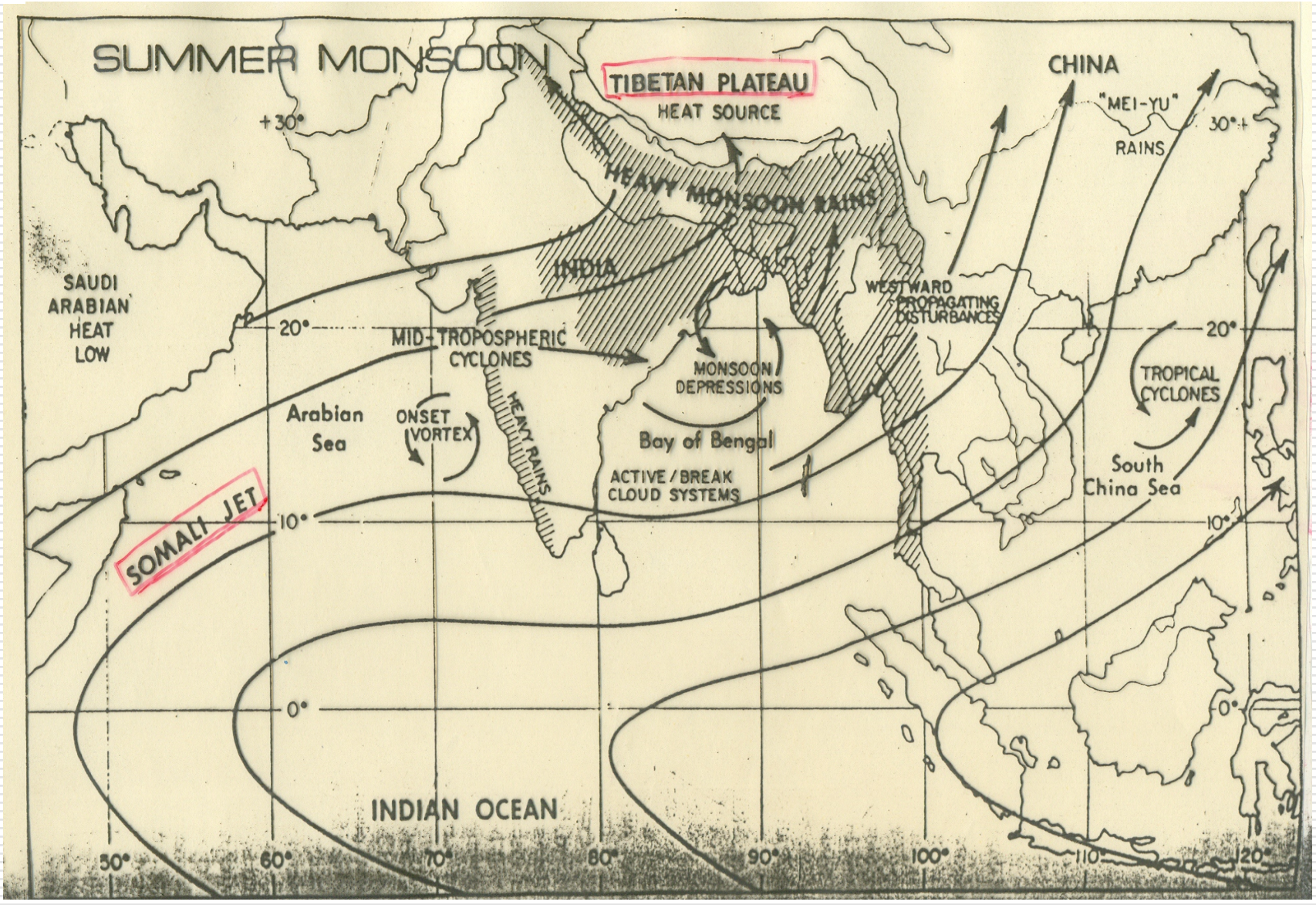
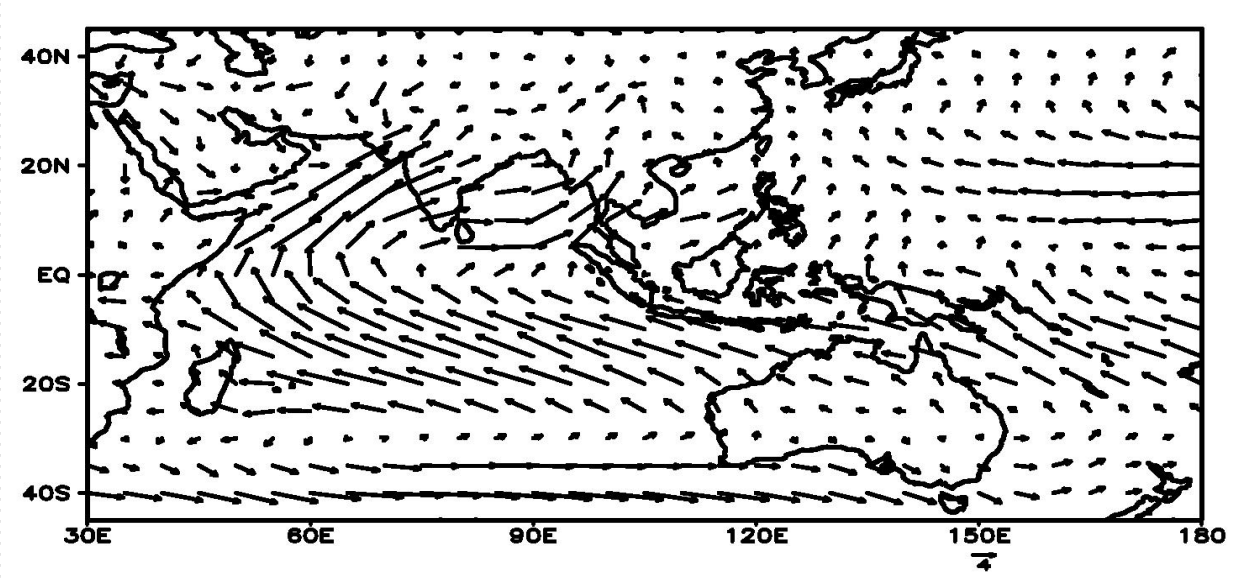
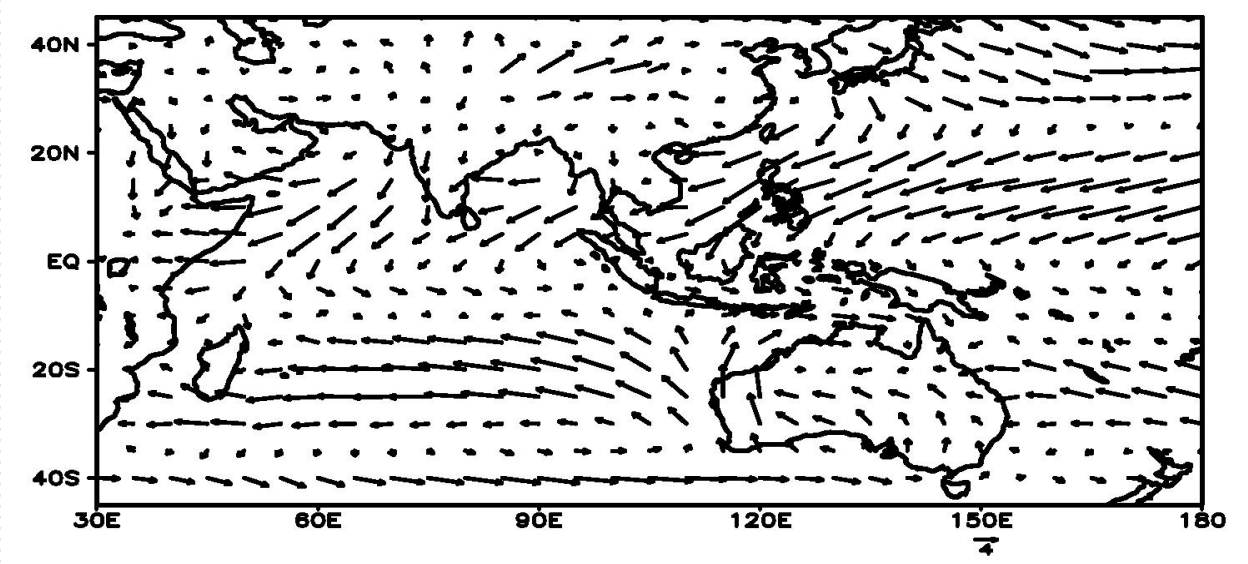
Outline of the talk

- Weakening of Indian Summer Monsoon based on observations
- Validation of RegCM SA CORDEX Simulations over India
- Future Projections indicating weakening of summer monsoon


SUMMER MONSOON
TIBETAN PLATEAU
HEAT SOURCE
CHINA
"MEI-YU"
RAINS
+30°
30°+
HEAVY MONSOON RAINS
INDIA
SAUDI
ARABIAN
HEAT
LOW
20°
MID-TROPOSPHERIC
CYCLONES
WESTWARD
PROPAGATING
DISTURBANCES
MONSOON
DEPRESSIONS
TROPICAL
CYCLONES
Arabian
Sea
ONSET
VORTEX
HEAVY RAINS
Bay of Bengal
ACTIVE / BREAK
CLOUD SYSTEMS
South
China Sea
SOMALI JET
10°
0°
INDIAN OCEAN
50°
60°
70°
80°
90°
100°
110°
120°

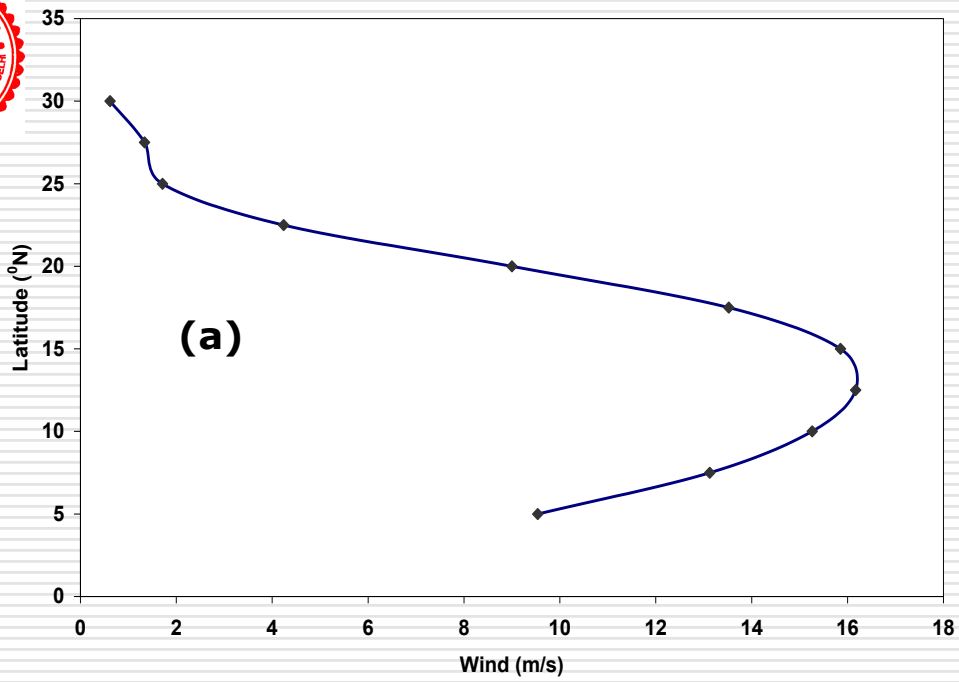


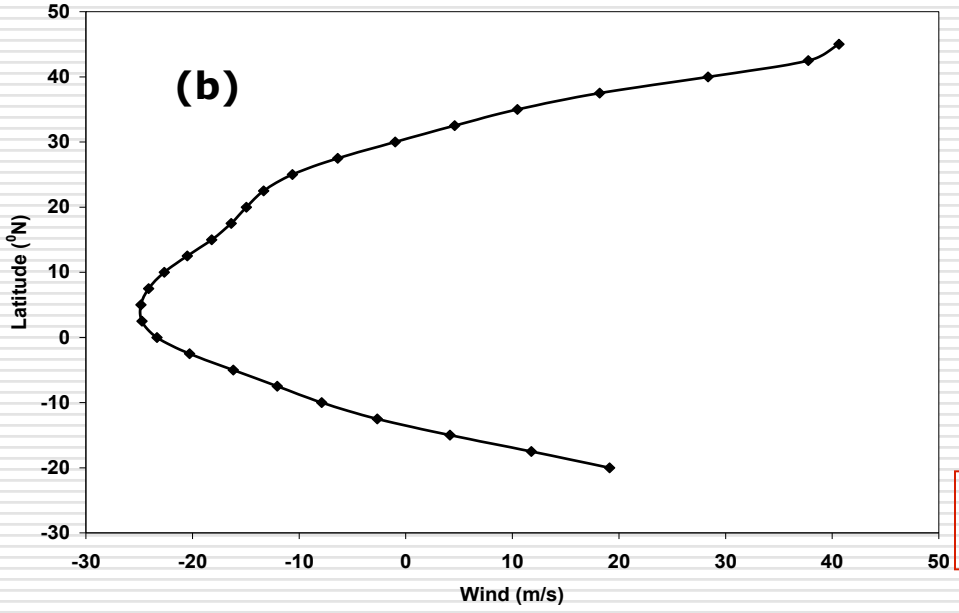
(a)



(b)

Surface wind (m/s) in the Indian region (a) June, July and August average (b) December, January and February average based on NCEP/NCAR reanalysis data.





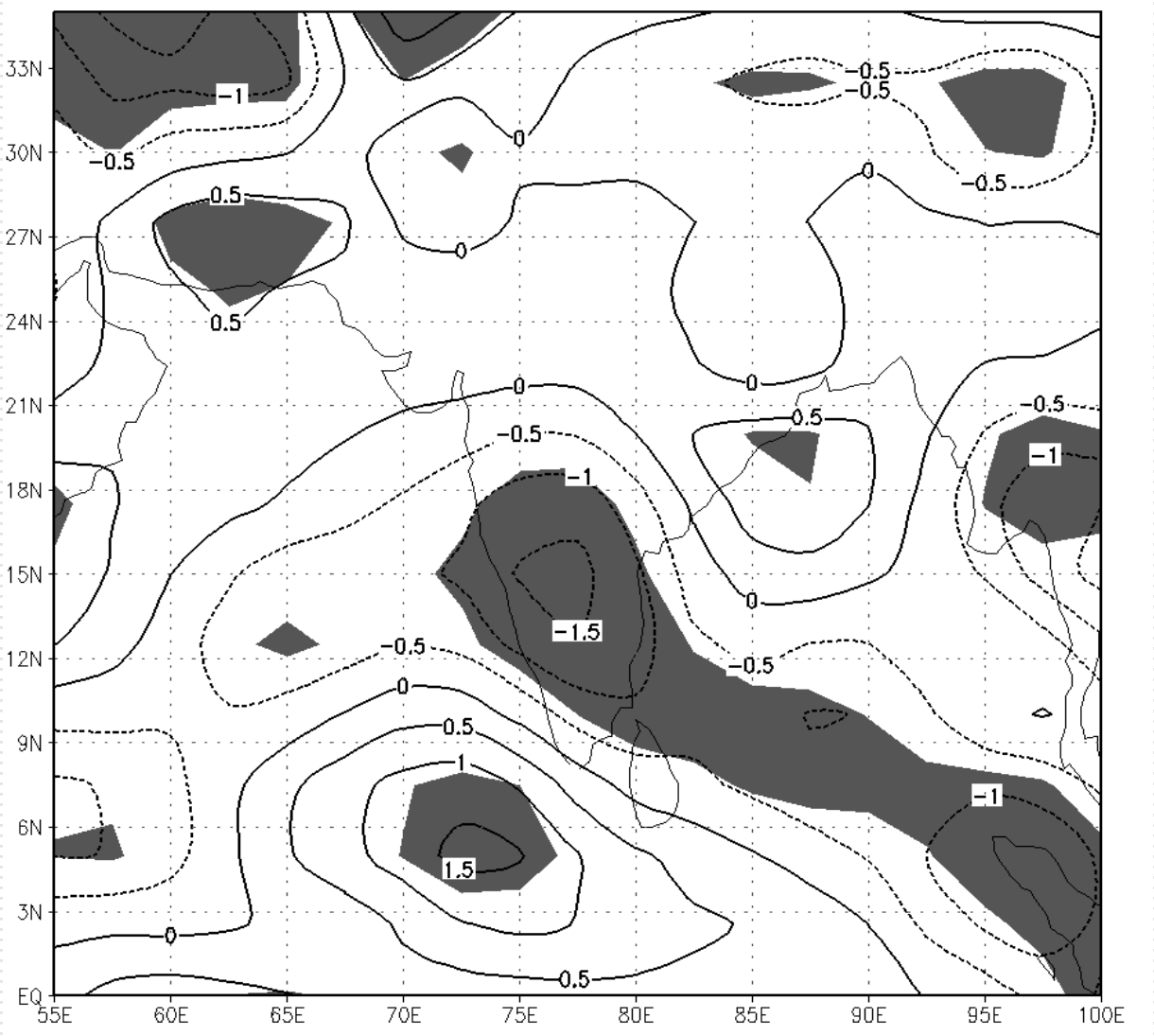
Latitudinal variation of zonal wind component in July over Indian region between

55⁰E-95⁰E

a)850 hPa

b)200 hPa

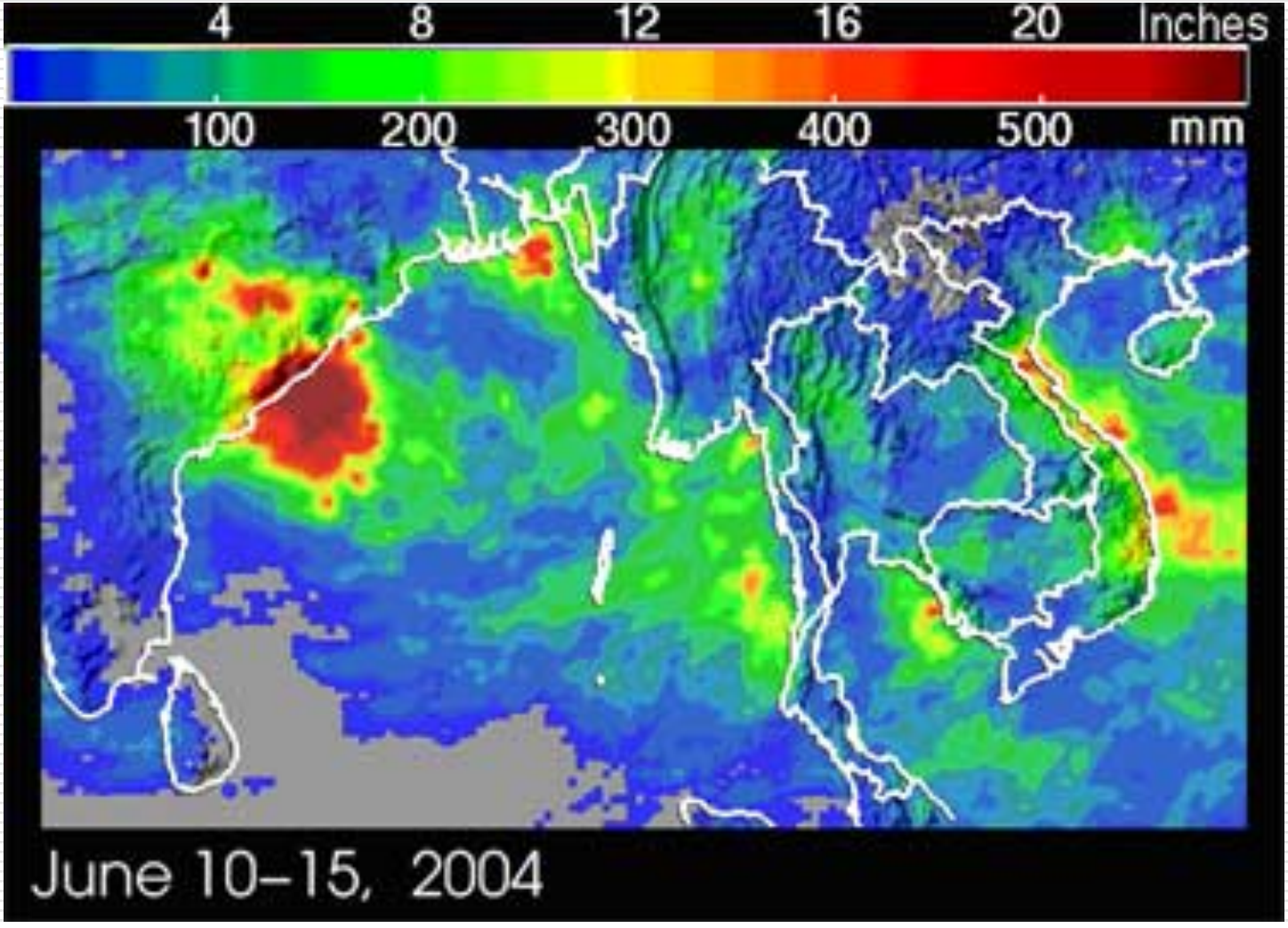
Dash et al., 2004, Current Science,86(10), 1404-1411.



Difference between the 850hPa mean monsoonal wind speeds in the two decades (1991-2000) and (1951-1960). The shaded region shows the significant change calculated using t test at 5% level.

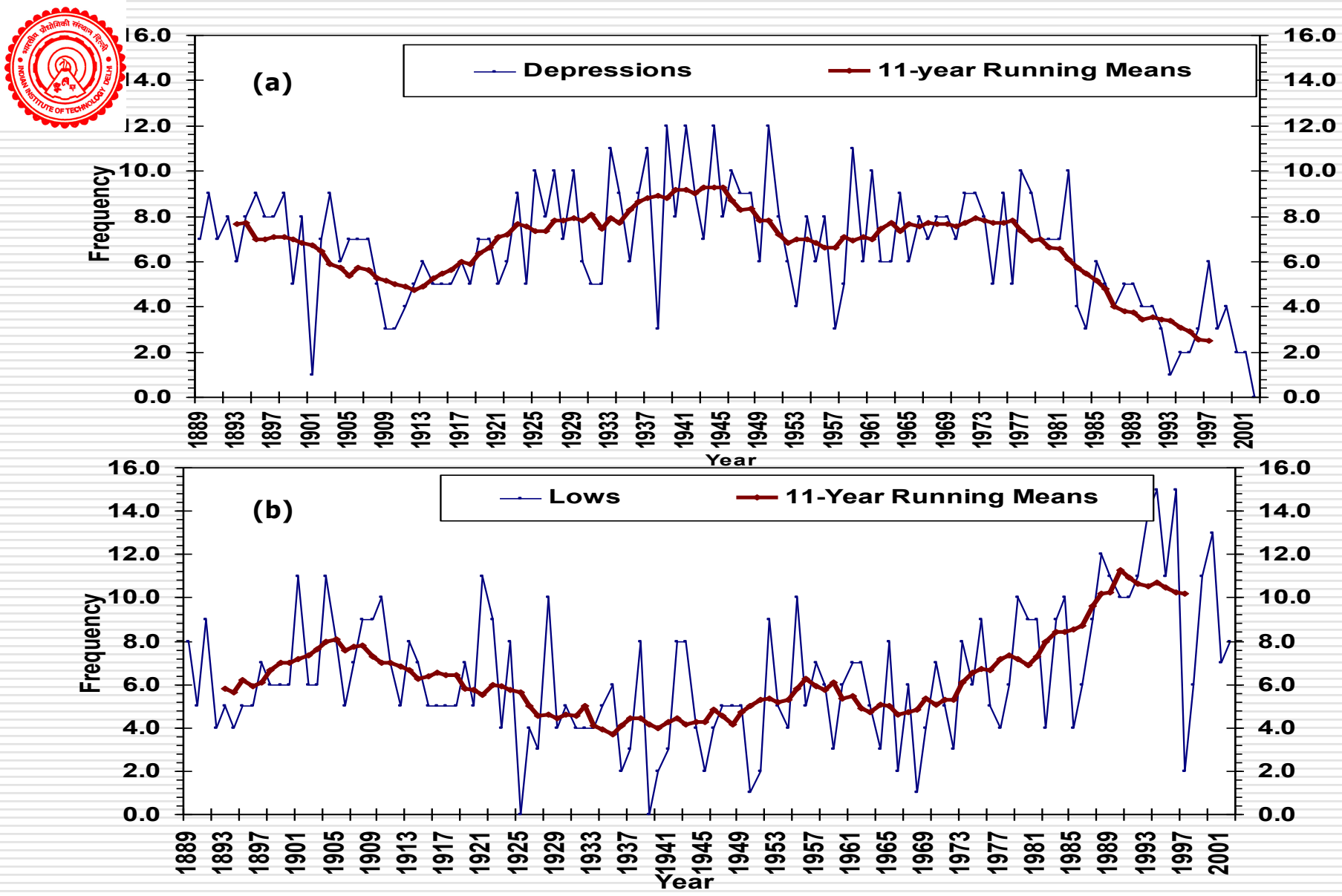
Dash et al. 2009 J. Geophys. Res. Vol.114

Monsoon Depression & Rainfall



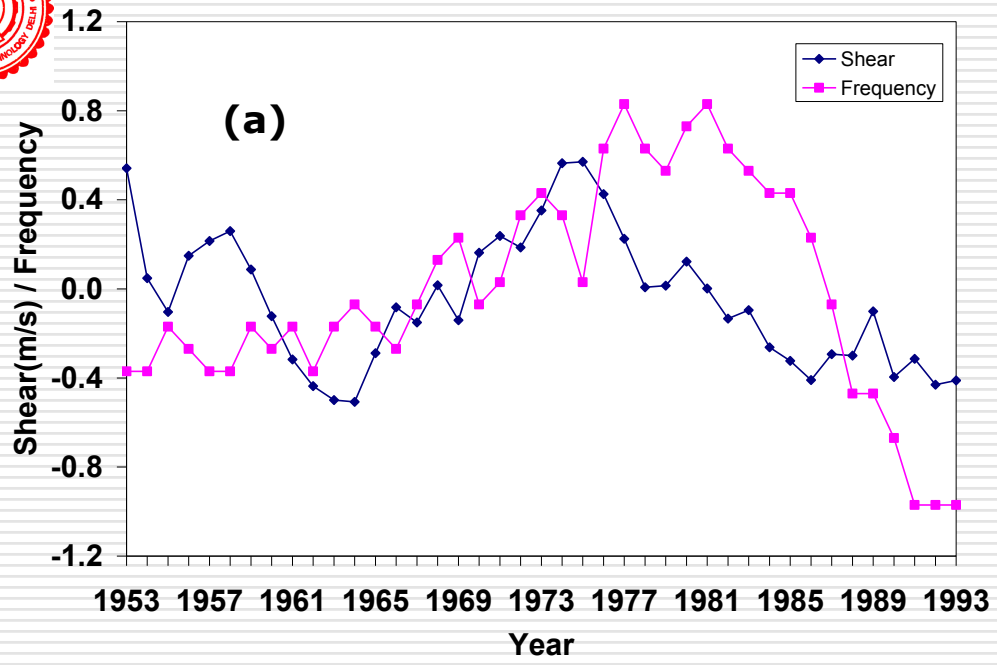
Categorisation of Cyclonic Disturbances

System	Pressure deficient hPa	Associated wind speed Knots (Kmph)
Low pressure area	1.0	<17(<31)
Depression	1.0- 3.0	17-27 (31–49)
Deep Depression	3.0 - 4.5	28-33 (50–61)
Cyclonic Storm	4.5- 8.5	34-47 (62-87)
Severe Cyclonic Storm (SCS)	8.5-15.5	48-63 (88-117)
Very Severe Cyclonic Storm	15.5-65.6	64-119 (118-222)
Super Cyclonic Storm	>65.6	>119(>222)

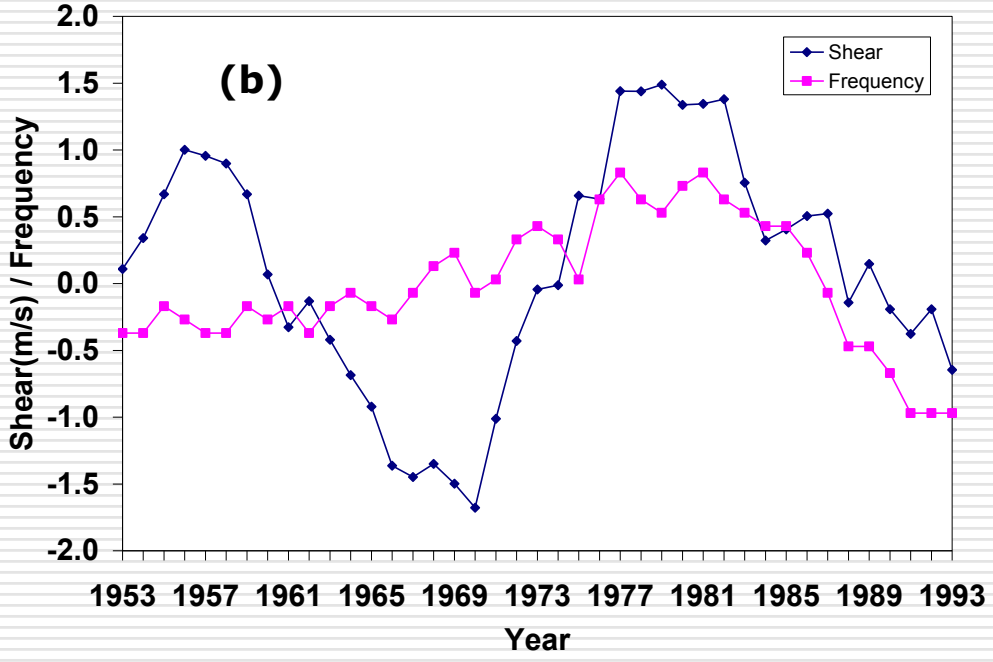


Eleven-year running means of annual frequency of disturbances with the minimum intensity of (a) monsoon depressions and (b) low pressure areas over the Indian region (1889-2003)

Dash et al., 2004, Current Science,86(10), 1404-1411.



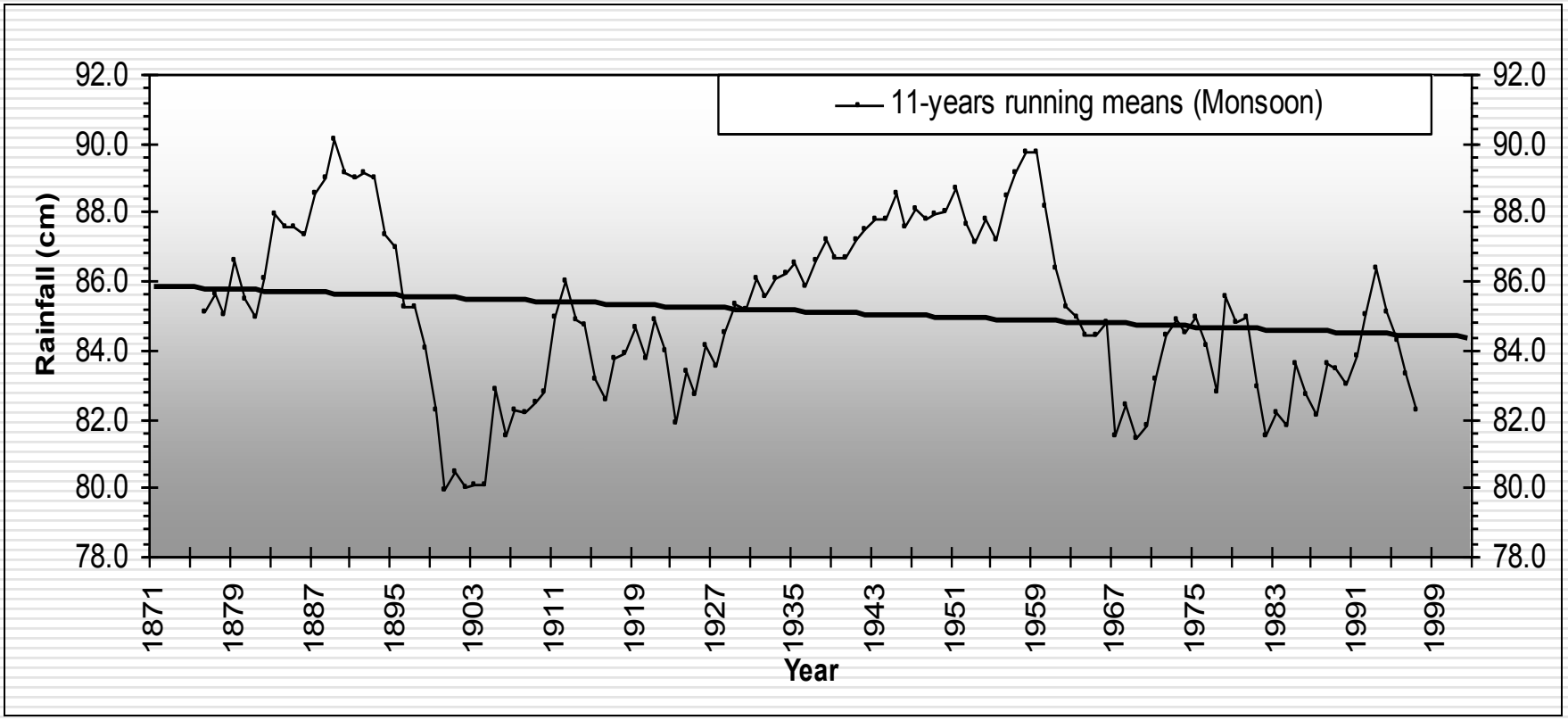
(a) 11-year running means of anomalies of horizontal wind shear at 850hPa in August between latitudes 0^0 and 25^0 N averaged over longitudes 55^0E to 95^0E.



(b) 11-year running means of vertical wind shear anomalies in August between

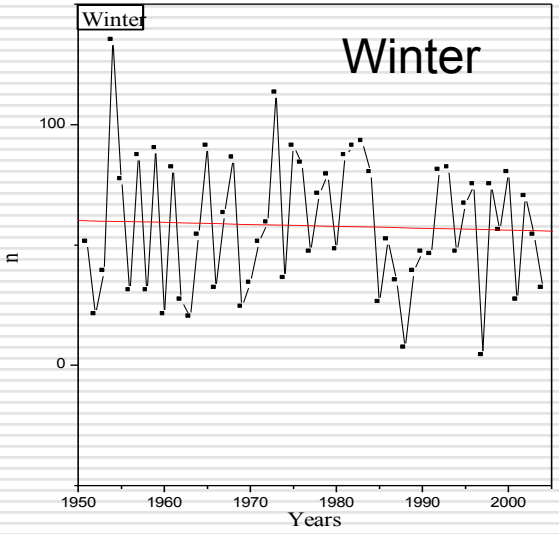
850&200 hPa levels averaged over the Indian region 0^0 to 25^0 N and 55^0E to 95^0E.

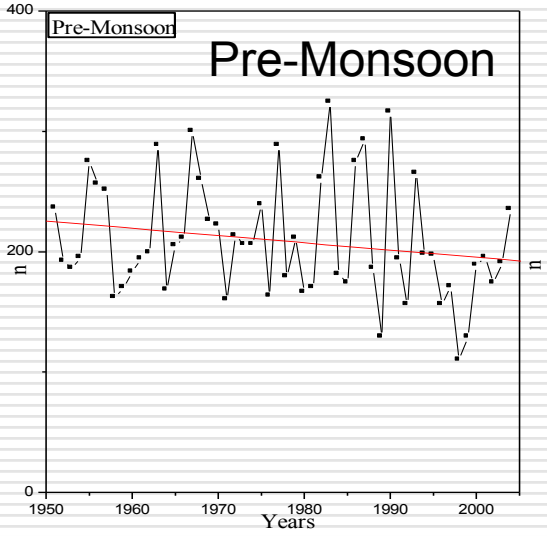
Dash et al., 2004, Current Science,86(10), 1404-1411.

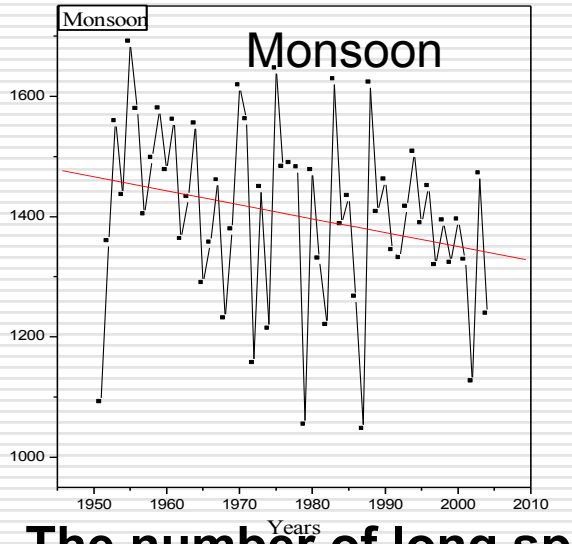


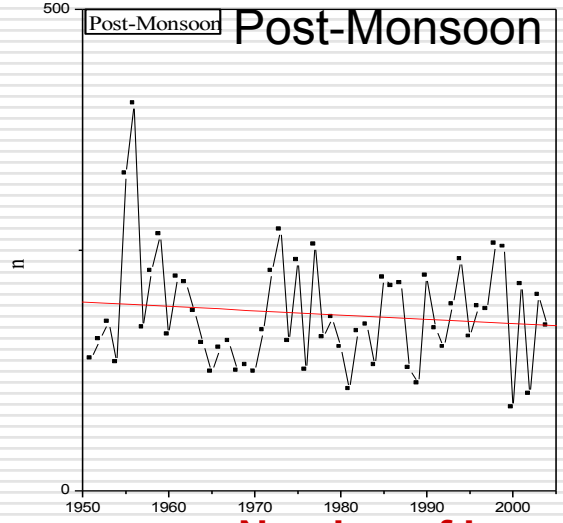
Time series of rainfall in India during monsoon months of June, July, August and September.

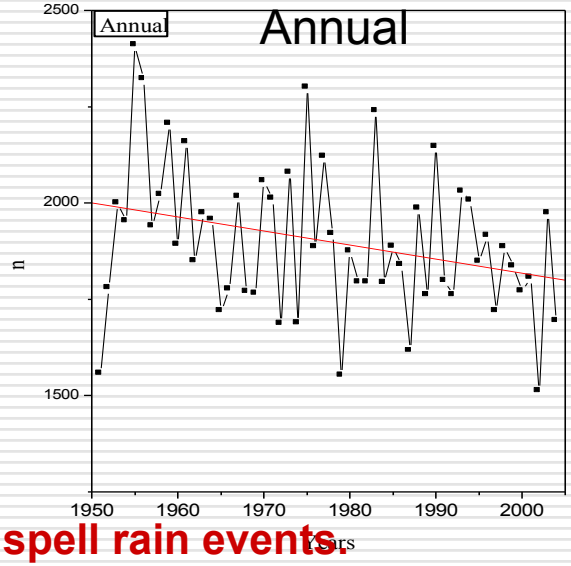
Dash et al., 2007, Climatic Change, DOI 10.1007











The number of long spell rainfall events shows decreasing trend in monsoon season in last 54 years. This suggests that synoptic scale systems and hence the southwest monsoon over the country may be weakening.

Number of long spell rain events.

Continuous rainfall for ≥4 days over all India in different seasons.

The red line is linear trend line.

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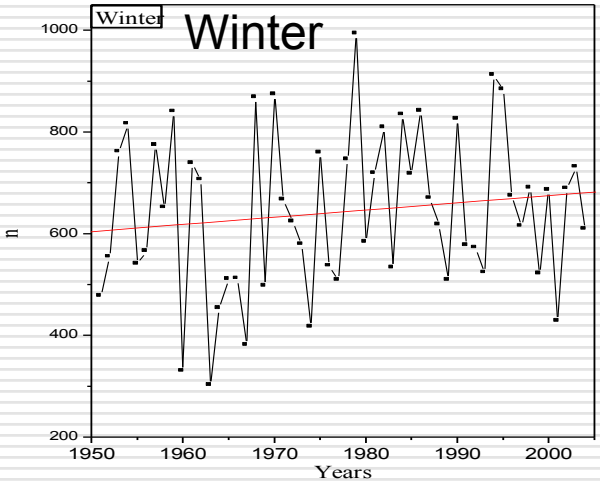

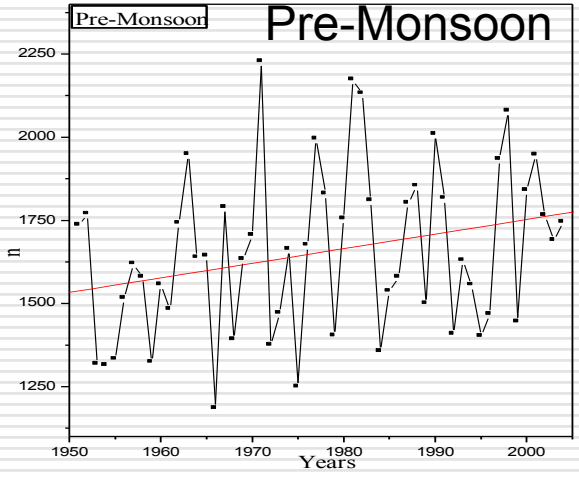

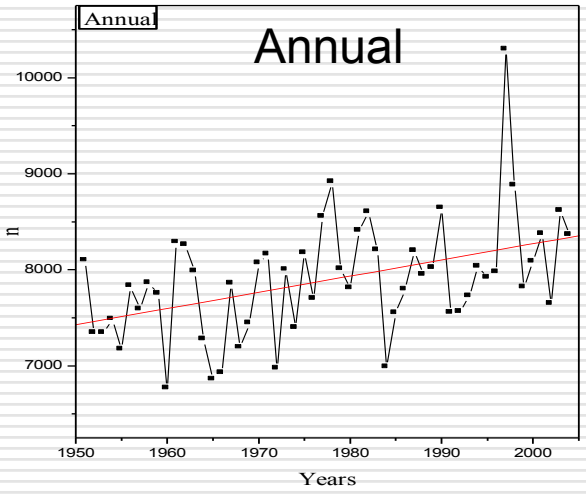

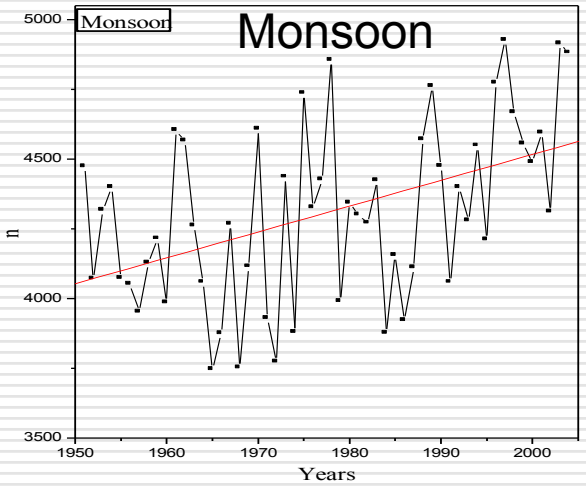

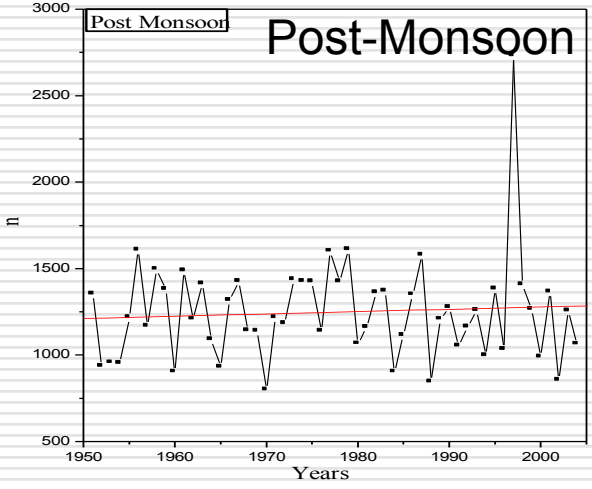

Number of short spell rain events (Continuous rainfall for < 4 days) over all India in different seasons. The red line is linear trend line.

Short spell rainfall events over India show increasing trend. This is an indication of increasing or intensifying of meso-scale convective systems.

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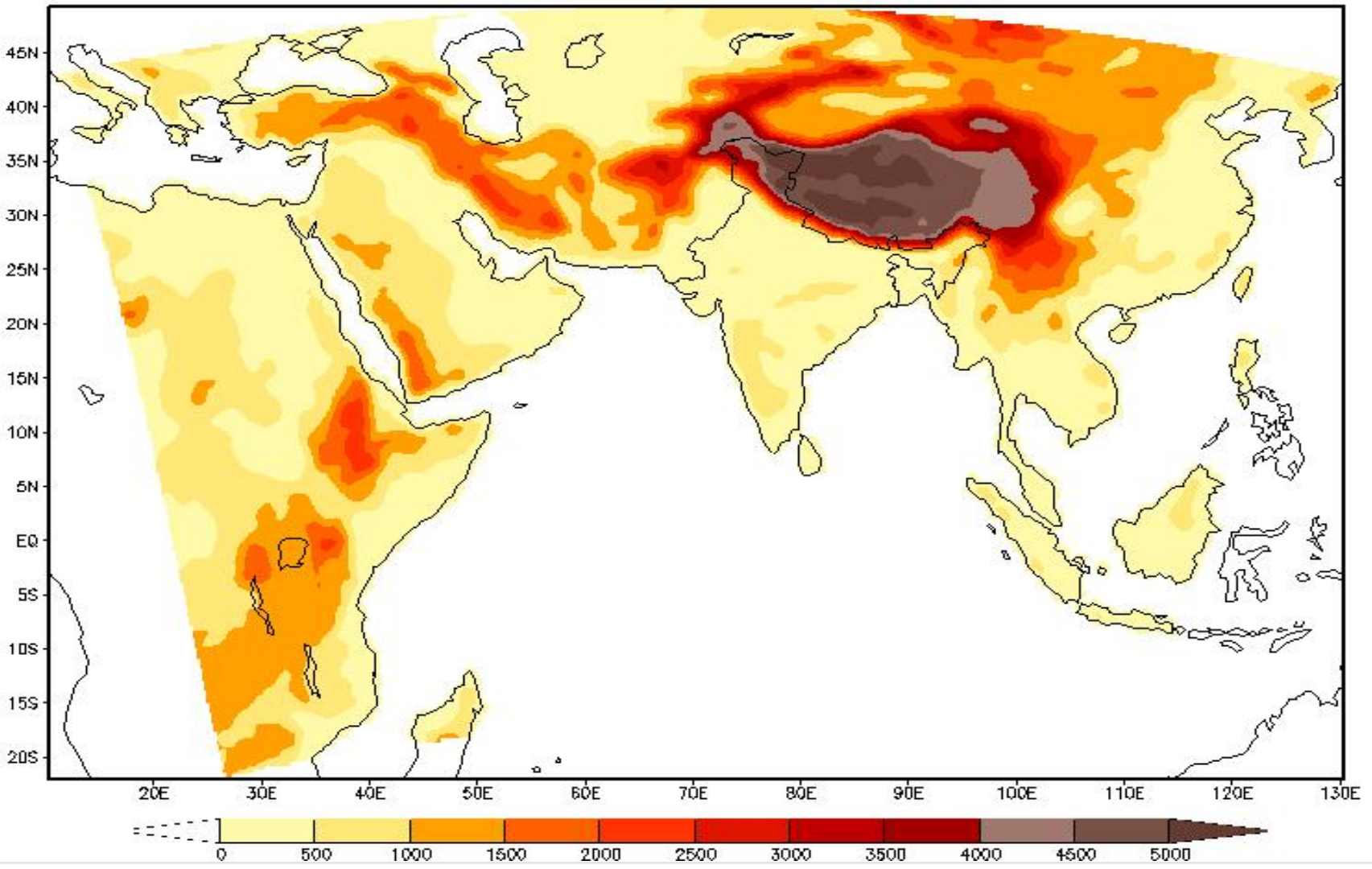
RegCM CORDEX Simulations

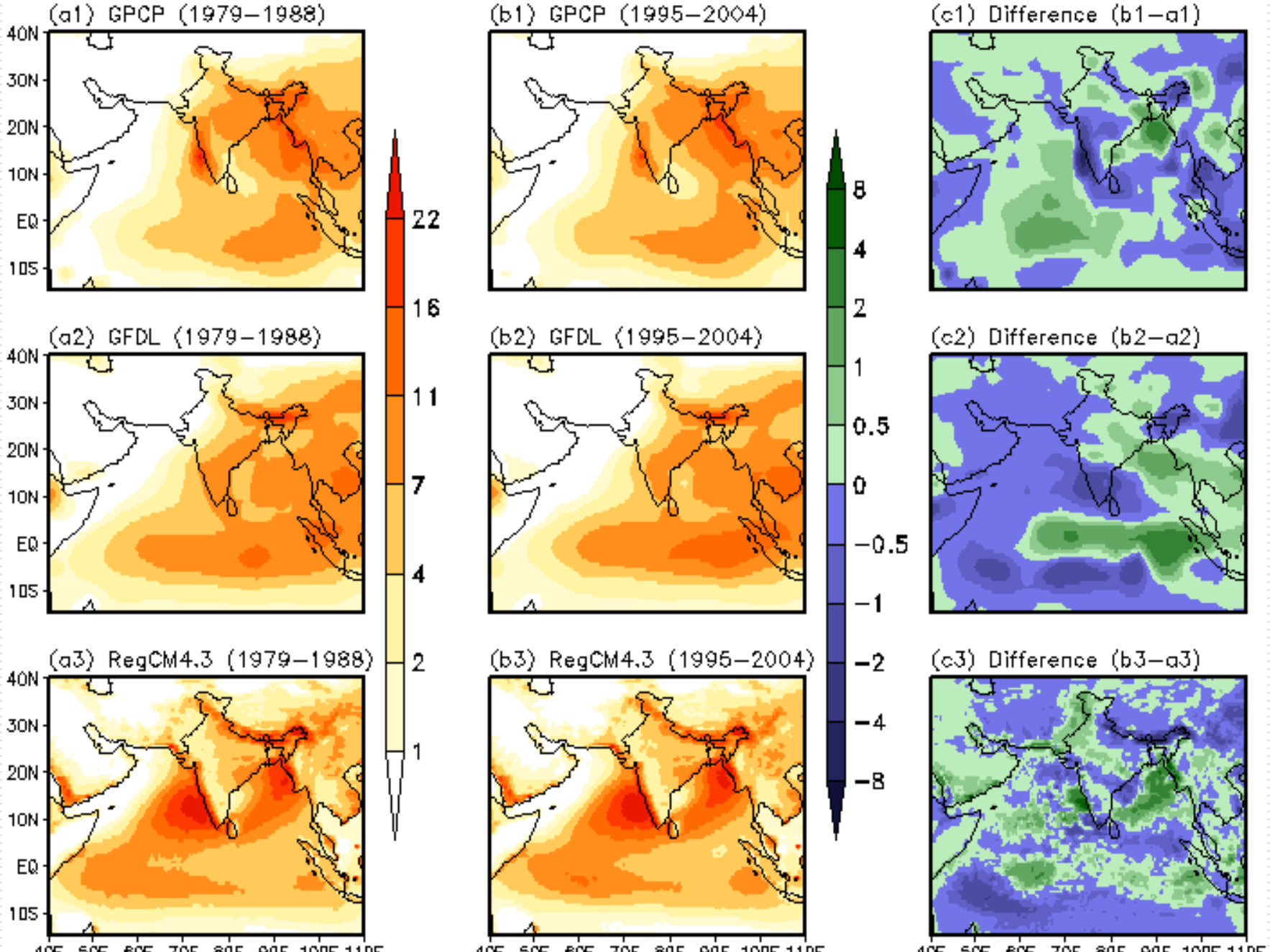
- Simulations with two GCM forcings GFDL-ESM2M and MPI-ESM-MR and RCP4.5 and RCP8.5 scenarios
- Reference period simulations 1979 to 2004
- Future projections 2010 to 2099
- Resolution of model output 50km
- Daily surface temperatures and rainfall are analyzed to some extent.

Model Domain

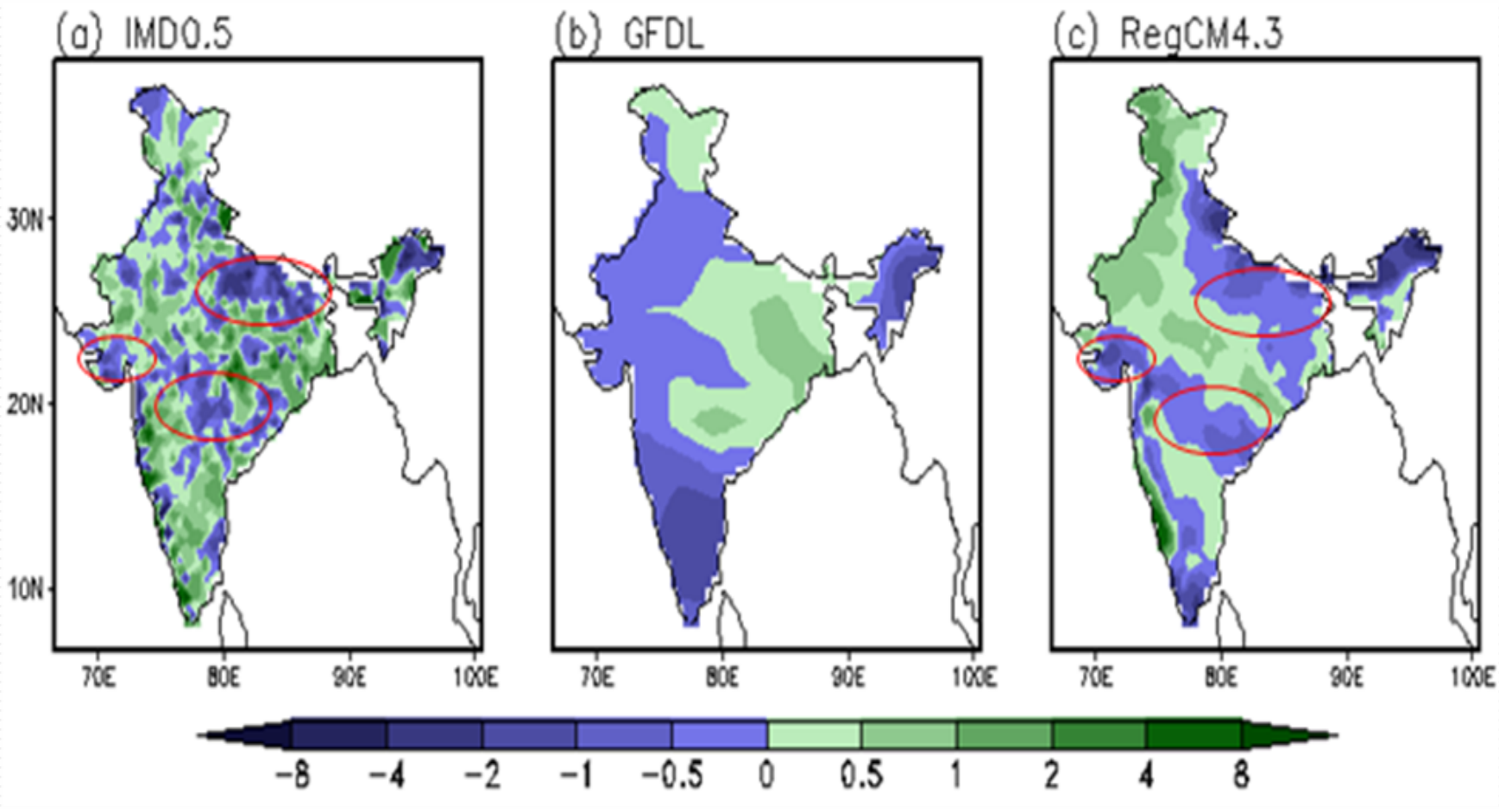


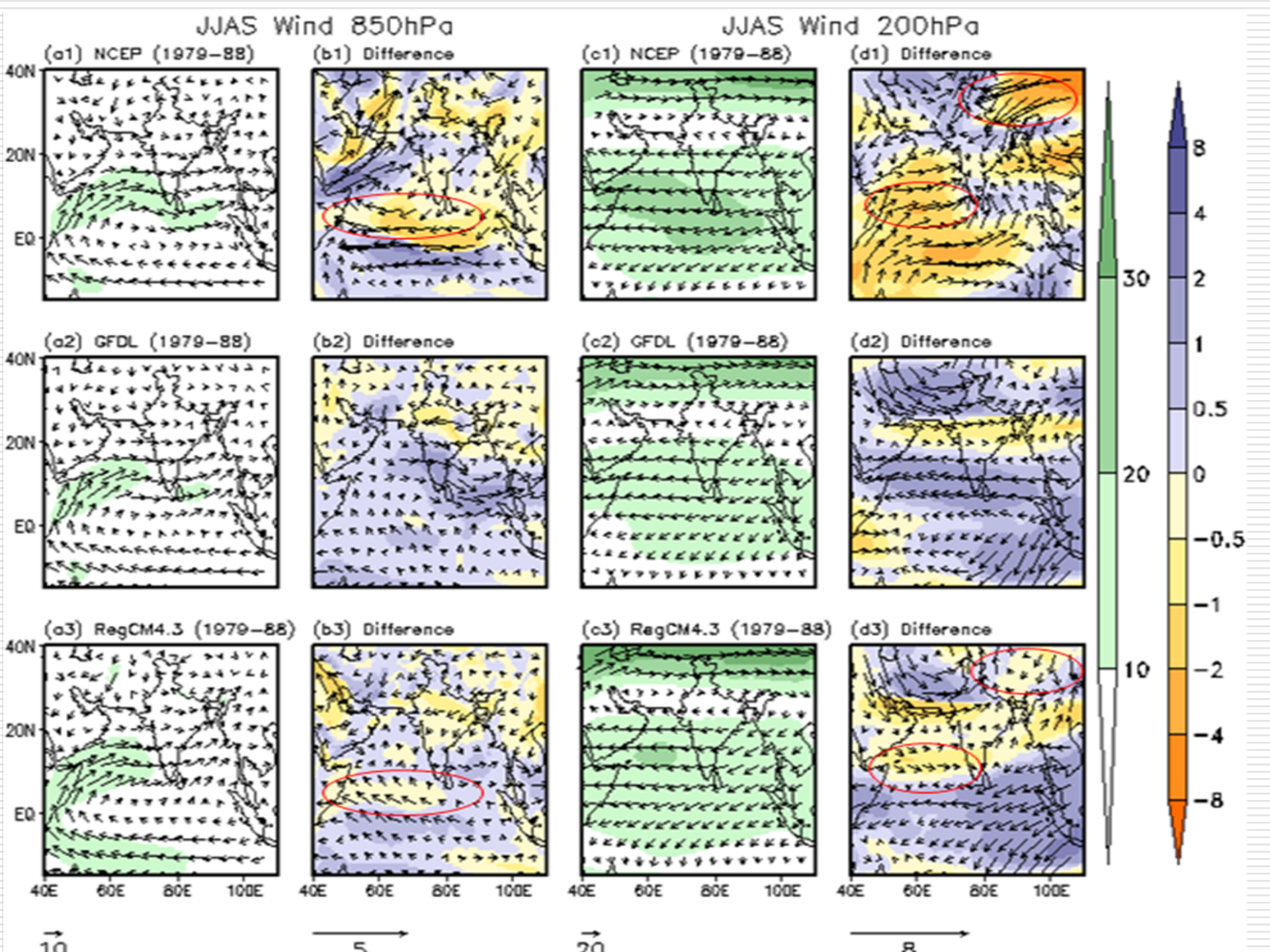
South Asia CORDEX Domain with topography (m) over which RegCM4.3 has been integrated

Decadal JJAS mean rainfall (mm/day) and the difference in rainfall between first and last decades during 1979 to 2004.

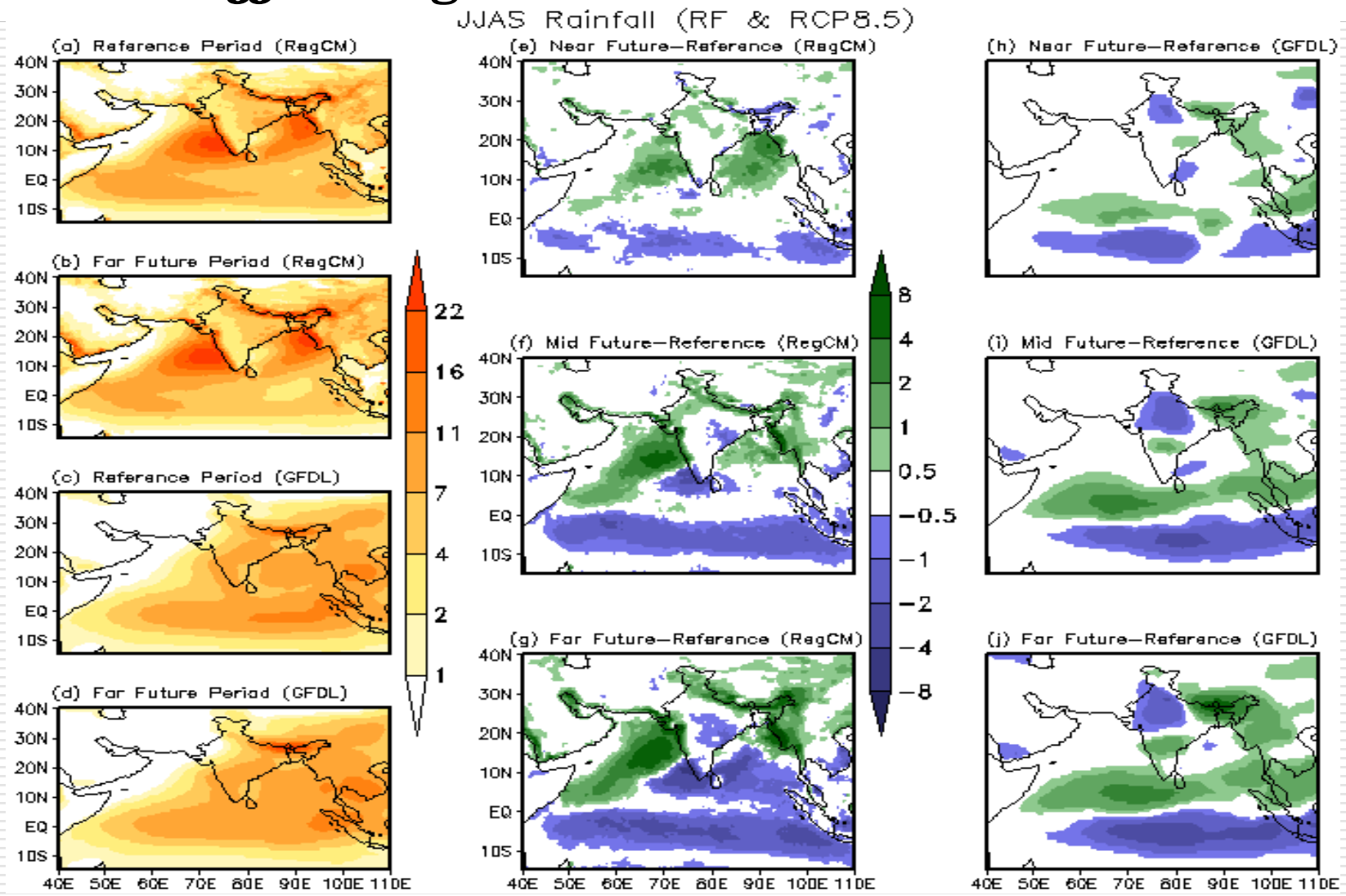


Decadal JJAS rainfall (mm/day) difference between first and last decades during 1979 to 2004



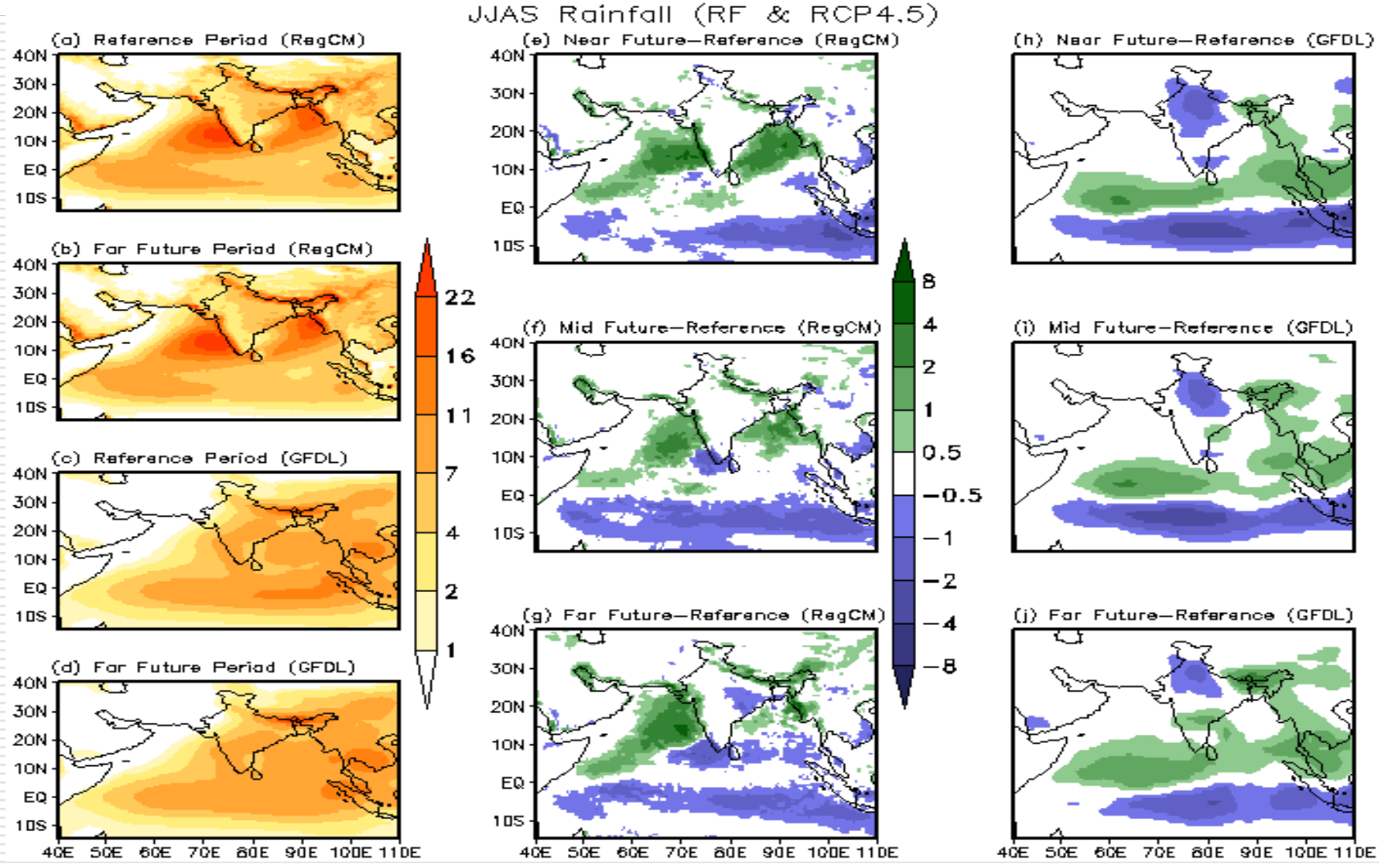

JJAS Wind 850hPa
JJAS Wind 200hPa
(a1) NCEP (1979–88)
(b1) Difference
(c1) NCEP (1979–88)
(d1) Difference
(a2) GFDL (1979–88)
(b2) Difference
(c2) GFDL (1979–88)
(d2) Difference
(a3) RegCM4.3 (1979–88)
(b3) Difference
(c3) RegCM4.3 (1979–88)
(d3) Difference
40N
20N
EQ
40E
60E
80E
100E
10
5
20
8
30
20
10
8
4
2
1
0.5
0
−0.5
−1
−2
−4
−8

JJAS RegCM4.3 Rainfall in RCP8.5



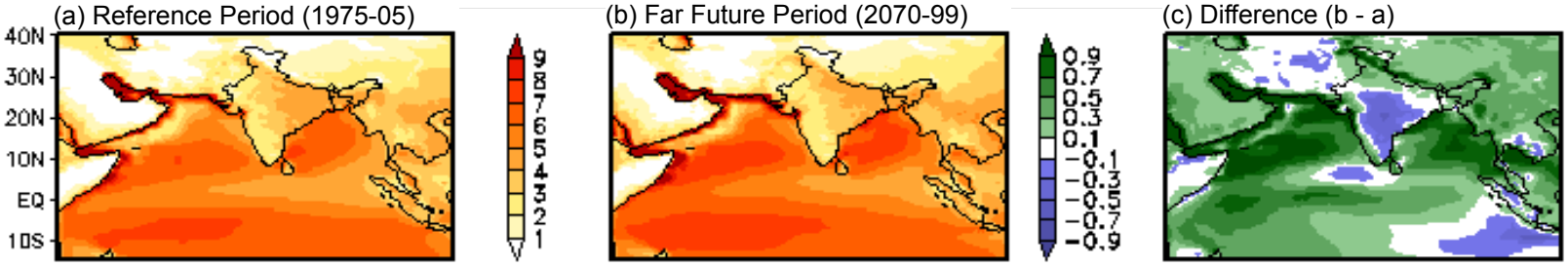
Mean summer monsoon rainfall (mm/day) during Reference Period (1975 to 2004), Near Future (2010 to 2039), Mid Future (2040 to 2069) and Far Future (2070 to 2099) periods as simulated by RegCM4.3 in RCP8.5

JJAS RegCM4.3 Rainfall in RCP4.5

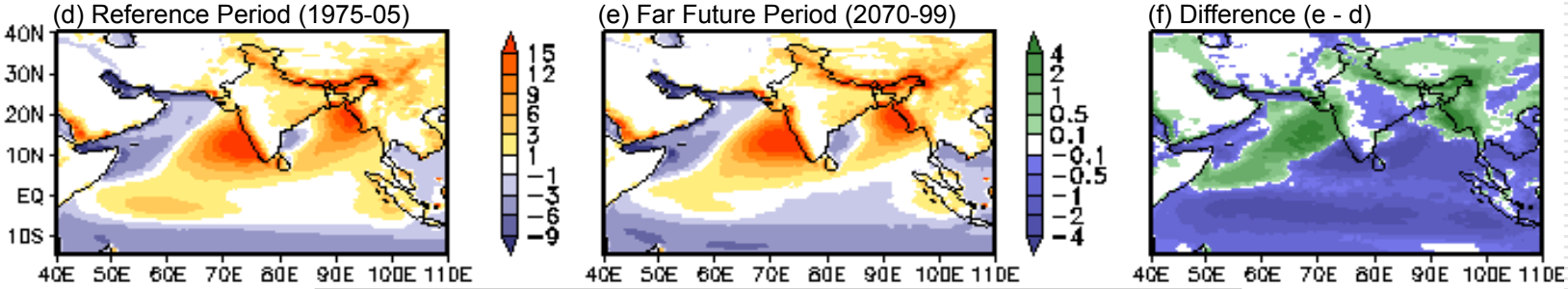


Mean summer monsoon rainfall (mm/day) during Reference Period (1975 to 2004), Near Future (2010 to 2039), Mid Future (2040 to 2069) and Far Future (2070 to 2099) periods as simulated by RegCM4.3 in RCP4.5

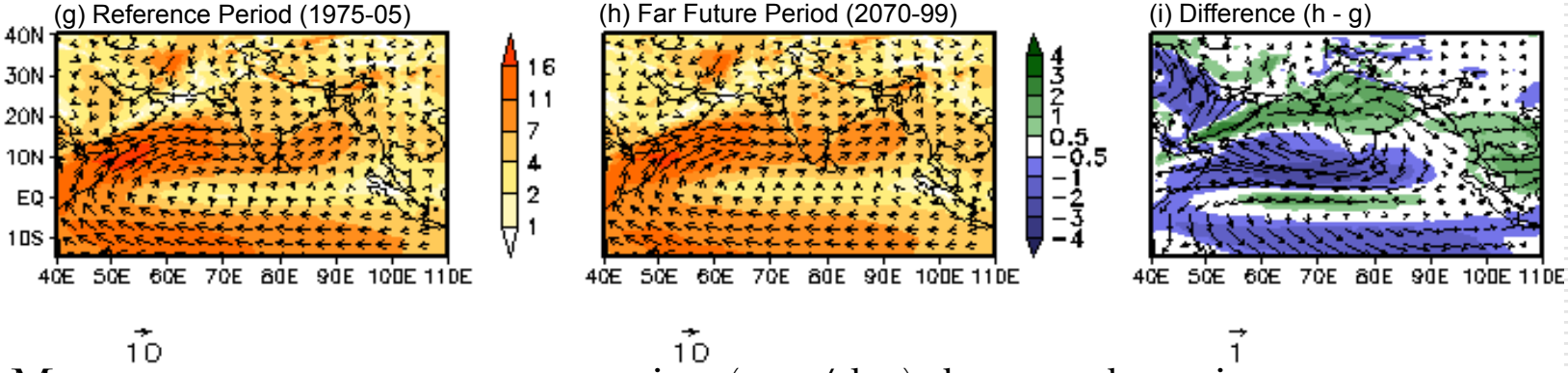
Evaporation



Large Scale Moisture Convergence

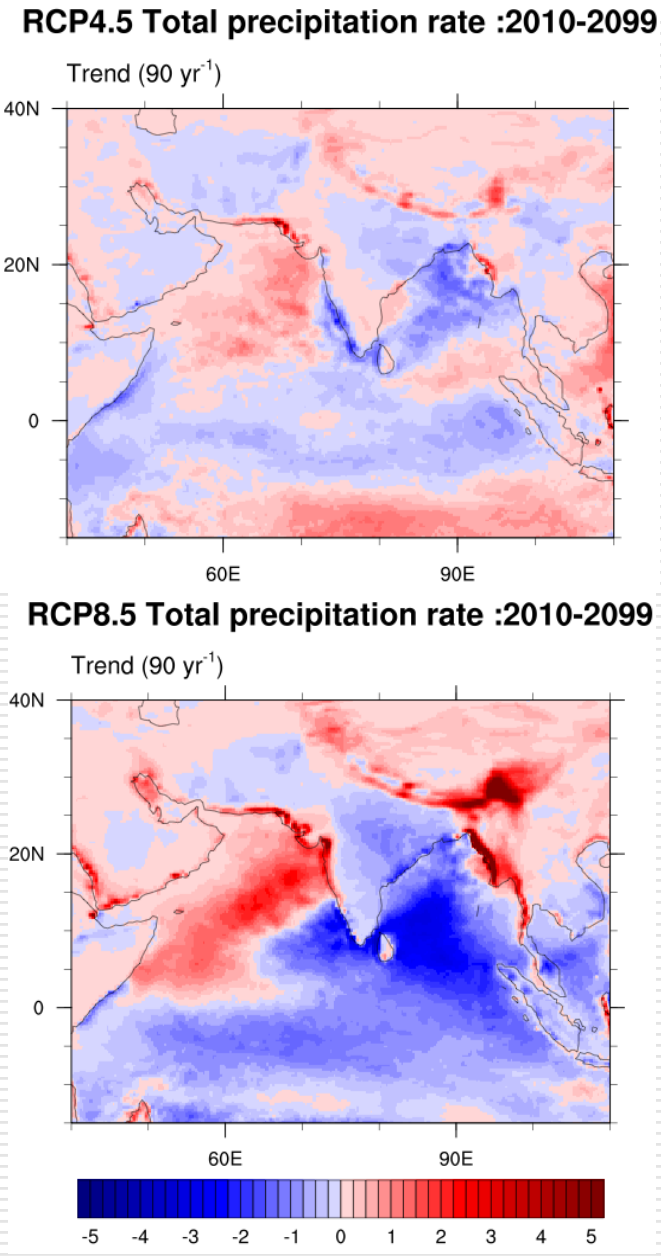


Wind at 850 hPa



Mean summer monsoon evaporation (mm/day), large scale moisture convergence (mm/day), and wind (m/s) at 850 hPa during Reference Period and Far Future scenarios as simulated by the model

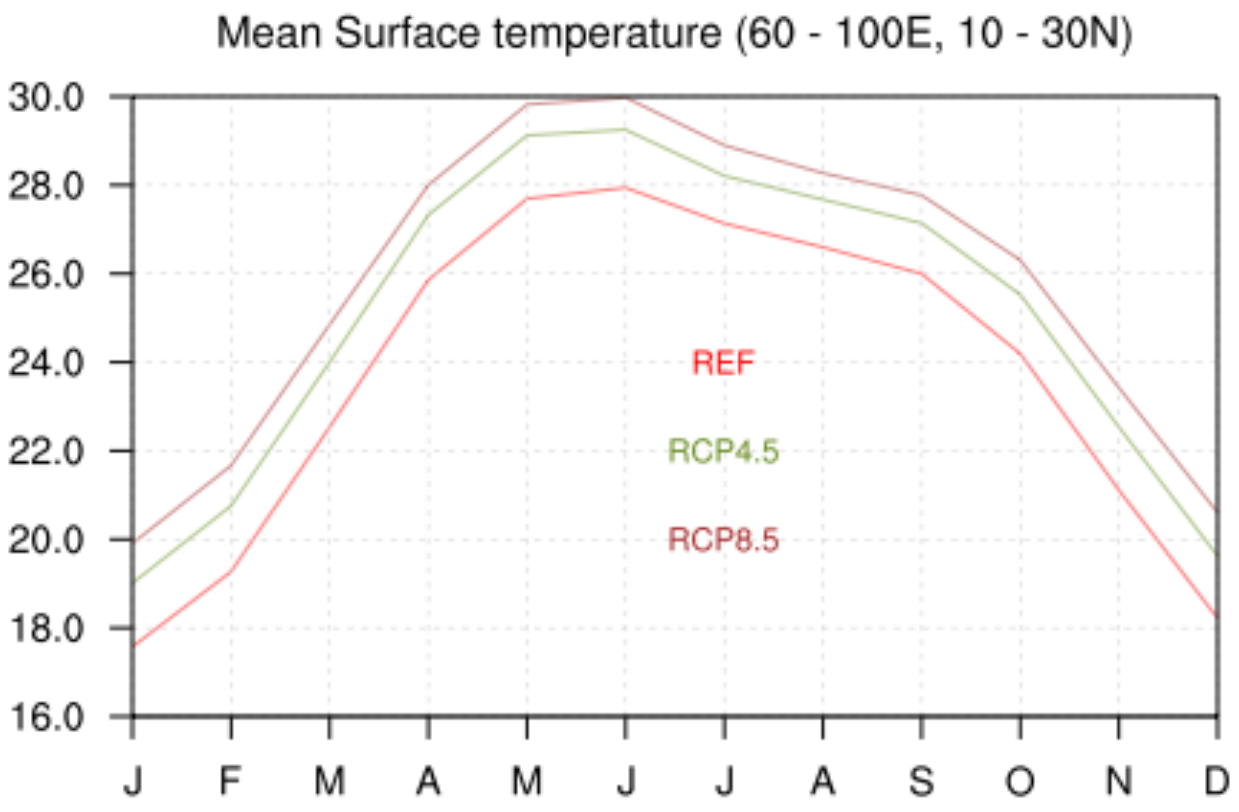
Total precipitation rate.



✓ In both the cases Bay of Bengal receives less precipitation and Arabian sea more.

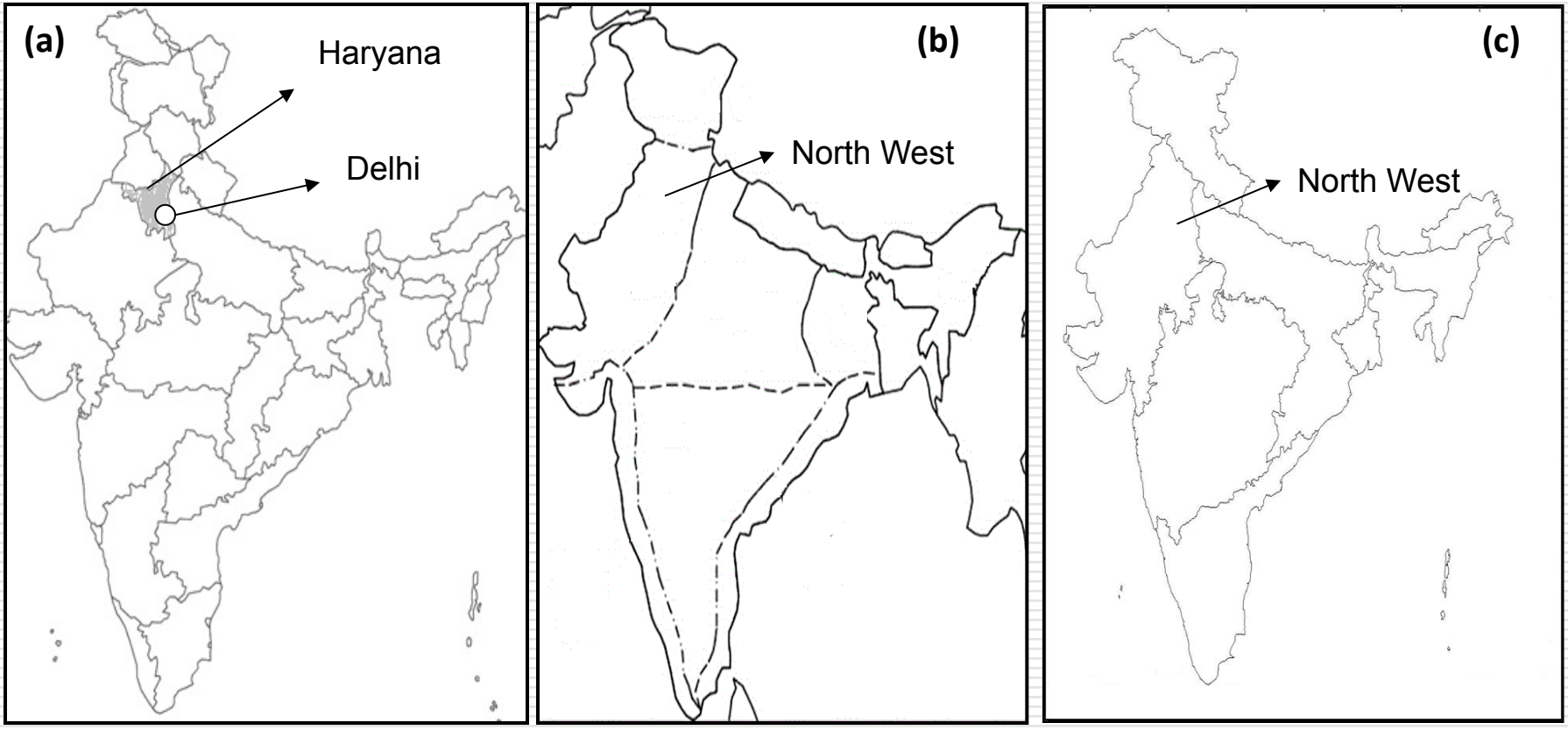
✓ Indian land area indicates decreasing rainfall trend in both the cases.

Surface temperature (degC)



- ✓ Reference period (REF) is for 1975-2005
- ✓ RCP4.5 & RCP8.5 are for 2010-2099.

Delhi and corresponding (a) Meteorological subdivision (b) Temperature Homogeneous zone and (c) Rainfall homogeneous zone



Comparison of maximum and minimum temperatures sand temperature extremes during 1975-2000 between IMD observed, IMD gridded and RegCM4.3

Categories of temperature		City			Meteorological Subdivision		Temperature Homogeneous Zone	
		Delhi			Haryana		North west	
		IMD Observed	IMD Gridded	RegCM4.3	IMD Gridded	RegCM4.3	IMD Gridded	RegCM4.3
Maximum Temperatures		+	+	⇧	+	⇧	+	⇧
Minimum Temperatures		+	⇧	⇧	⇧	⇧	⇧	⇧
Warm Days	TX90p	+	+	+	+	+	+	⇧
	TX95p	+	+	+	+	+	+	▲
	TX99p	+	+	+	+	+	+	+
Cold Days	TX10p	+	⇧	-	△	-	△	-
	TX05p	+	▲	-	+	-	+	-
	TX01p	-	△	-	+	-	+	-
Warm Nights	TN90p	-	+	+	+	+	+	+
	TN95p	-	+	+	+	+	+	+
	TN99p	+	+	+	+	+	+	+
Cold Nights	TN10p	+	▼	-	▼	-	▽	-
	TN05p	+	▽	-	▼	-	▼	-
	TN01p	+	-	-	-	-	-	-

Increasing (Decreasing) trends significant at 10%,5% and 1% levels are marked by the symbols △, ▲ and ⇧ (▽,▼ and ⇩) respectively and +(-) indicates increasing(decreasing) trend but not statistical significant.

Comparison of JJAS mean rainfall and rainfall extremes during 1975-2005 between IMD observed, IMD gridded and RegCM4.3

Categories of Rainfall events	City (Delhi)			Meteorological Subdivision (Haryana)		Homogenous Zone (North West)	
	Station Data	IMD Gridded	RegCM4.3	IMD Gridded	RegCM4.3	IMD Gridded	RegCM4.3
Mean JJAS Rainfall	-	▽	-	-	-	-	-
Low	+	-	-	-	-	-	▼
Moderate	△	-	-	-	-	-	-
Heavy	+	-	-	-	+	-	+

Increasing (Decreasing) trends significant at 10%,5% and 1% levels are marked by the symbols △, ▲ and ⇧ (▽,▼ and ⇩) respectively and +(-) indicates increasing(decreasing) trend but not statistical significant.

Summary of future projections of temperature, rainfall and their extremes during 2015-2044 based on RegCM4.3 simulations

Categories of temperature		City (Delhi)	Meteorological Subdivision (Haryana)	Homogeneous Zone (North West)
Maximum Temperature		+	+	+
Minimum Temperature		▲	▲	⇧
Warm Days	TX90p	+	+	-
	TX95p	+	+	-
	TX99p	+	+	-
Cold Days	TX10p	⇩	-	-
	TX05p	▼	-	-
	TX01p	-	-	-
Warm Nights	TN90p	+	+	+
	TN95p	+	+	+
	TN99p	+	+	+
Cold Nights	TN10p	▽	▽	▽
	TN05p	▼	-	-
	TN01p	-	-	-

Categories of Rainfall events	City (Delhi)	Meteorological Subdivision (Haryana)	Homogenous Zone (North West)
JJAS mean rainfall	+	△	+
Low intensity	-	+	
Moderate intensity	-	-	
Heavy intensity	+	+	+

Increasing (Decreasing) trends significant at 10%,5% and 1% levels are marked by the symbols △, ▲ and ⇧ (▽,▼ and ⇩) respectively and +(-) indicates increasing(decreasing) trend without statistical significance

Robust signals obtained from RegCM4.3 in future projections at Delhi during 2015-2044

1	**Increase in annual minimum temperature in Delhi, meteorological subdivision Haryana and homogeneous zone Northwest. [Robust signal]**
2	**Increase in warm days & nights in Delhi and meteorological subdivision Haryana. [Somewhat robust signal]**
3	**Decrease in cold days & nights in Delhi, meteorological subdivision Haryana and homogeneous zone North West. [Robust signal]**
4	**Significant increase in JJAS mean rainfall at 10% level in subdivision Haryana. It also increase in Delhi and homogenous zone North West but without any statistical significance. [No robust signal]**
5	**Increase in heavy rainfall events in Delhi, subdivision Haryana and homogenous zone North West but without any statistical significance. [No robust signal]**

Conclusions

- **Based on observations, it may be inferred that Indian summer monsoon circulation is weakening and associated monsoon depressions are decreasing in number.**

- **Long duration rain spells are increasingly replaced by shorter duration heavy spells.**

- **The changes in the RegCM4.3 SA CORDEX simulated rainfall have followed the same patterns (increasing/decreasing) as that of the GFDL-ESMS2M in both RCP4.5 and RCP8.5 and the fine features of the rainfall pattern in the GFDL-ESMS2M have been intensified in the RegCM4.3 simulations**

- **In the future, the rainfall may steadily weaken over the Central India and strengthen over the Arabian Sea.**

Thank you for