Trends of monsoon circulation and rainfall : Role of natural variability

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Background

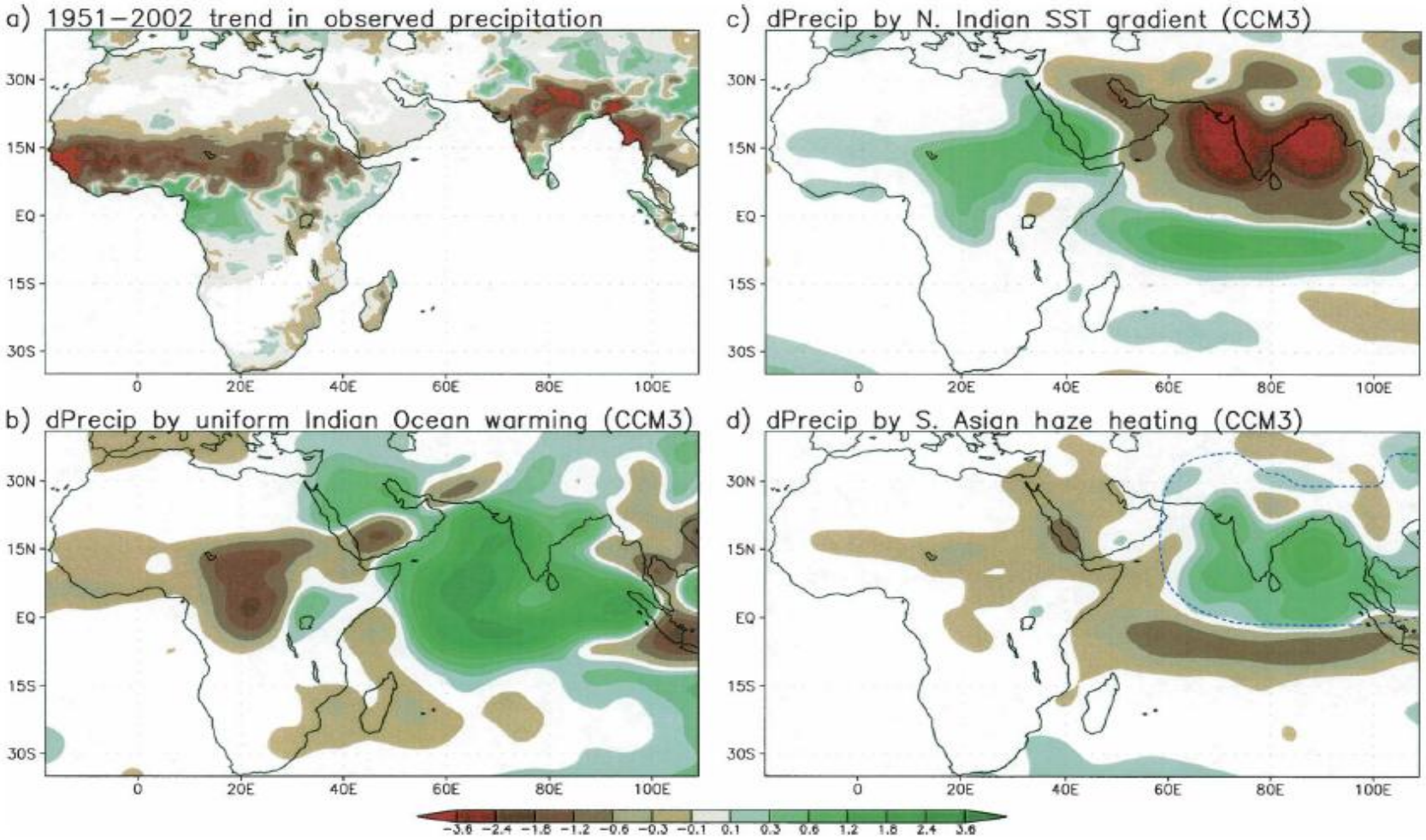
- With the projections of global warming, some changes are expected in monsoon circulation and rainfall.
- IPCC models generally indicate a strengthening of the monsoon due to increase in water vapour.
- The role of aerosols, especially black carbon aerosols on the Indian monsoon is uncertain.
- Observational studies suggested a weakening of the monsoon circulation and rainfall during the recent years (since 1951)
- Recent studies have attributed these changes to the changes in atmospheric constituents especially aerosols.

Weakening of North Indian SST Gradients and the Monsoon Rainfall in India and the Sahel

J Climate, 2006

CHUL EDDY CHUNG AND V. RAMANATHAN

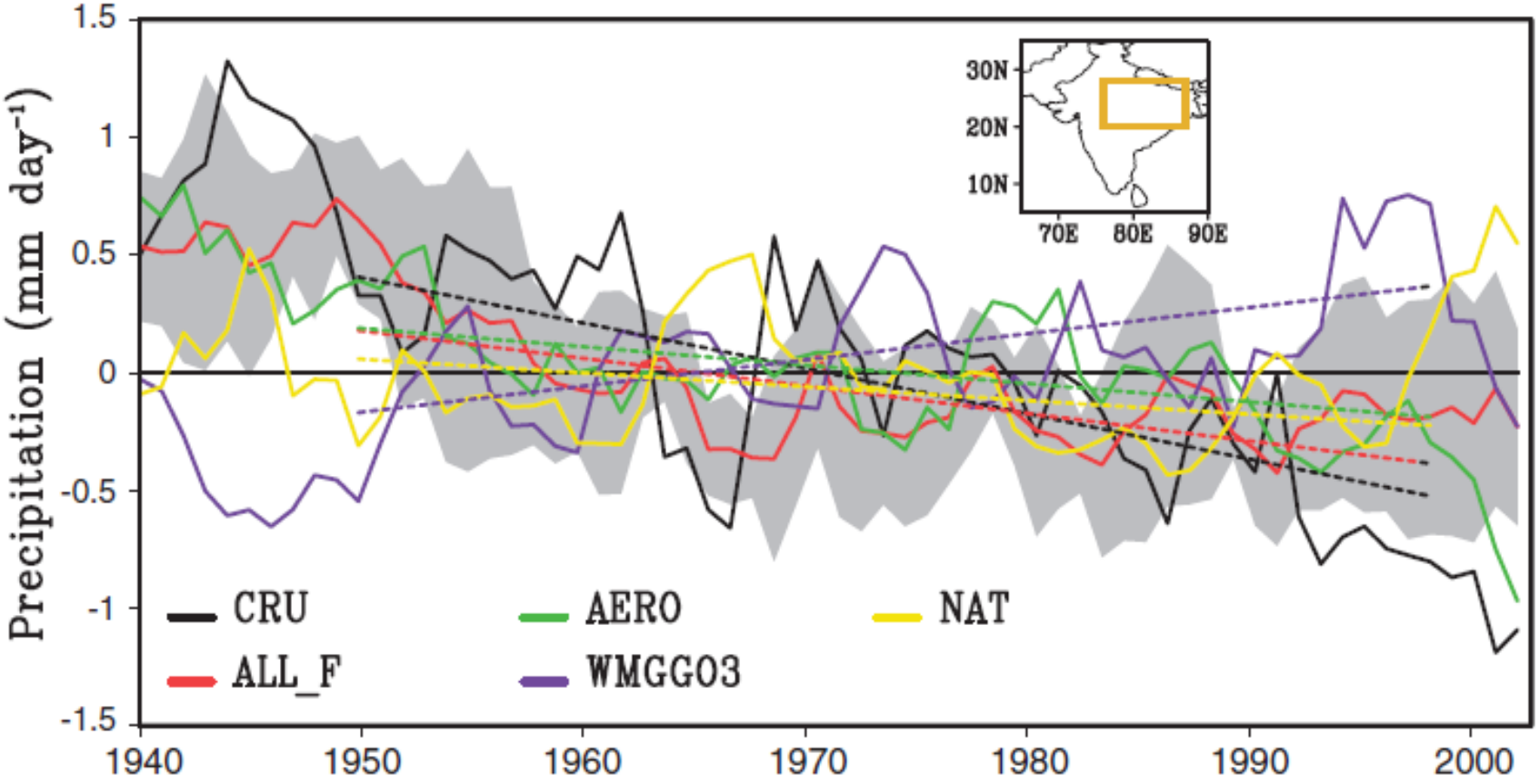
Center for Clouds, Chemistry, and Climate, Scripps Institution of Oceanography, La Jolla, California



Anthropogenic Aerosols and the Weakening of the South Asian Summer Monsoon

Massimo A. Bollasina,[1] Yi Ming,[2]* V. Ramaswamy[2]

Science, 2011

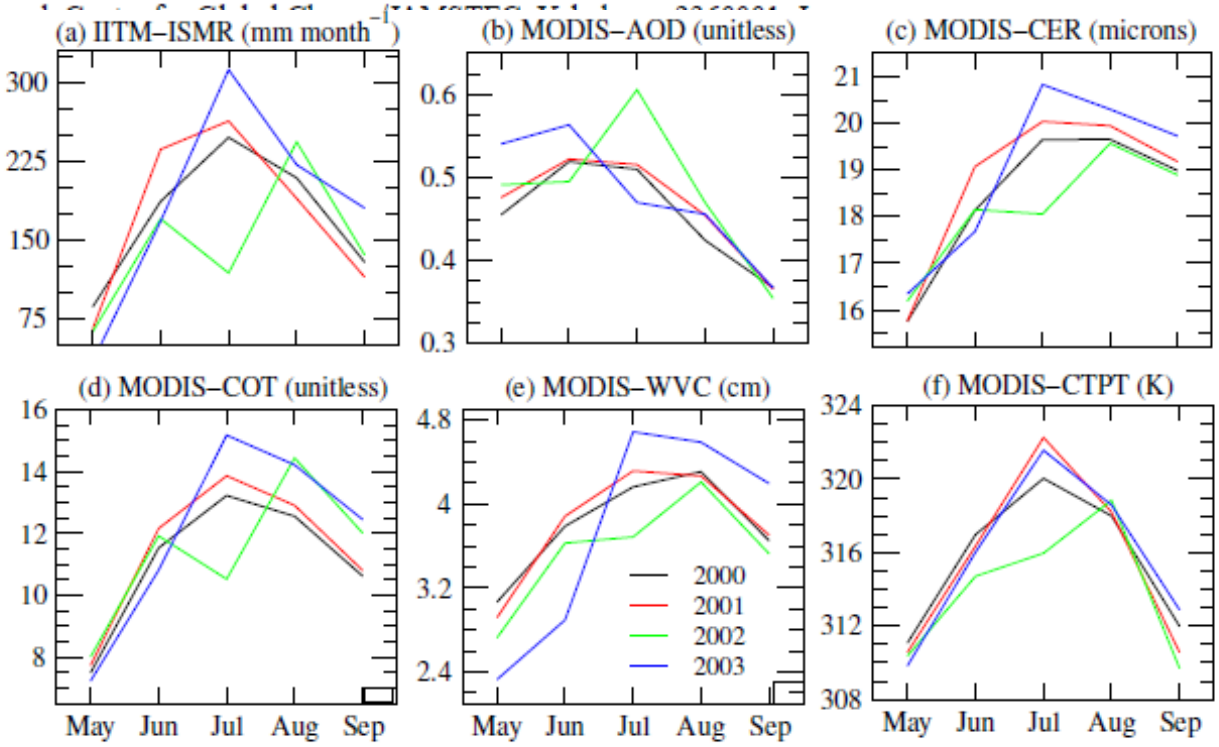


Atmos. Chem. Phys., 5, 2181–2188, 2005
www.atmos-chem-phys.org/acp/5/2181/
SRef-ID: 1680-7324/acp/2005-5-2181
European Geosciences Union

Atmospheric Chemistry and Physics

The Indian summer monsoon rainfall: interplay of coupled dynamics, radiation and cloud microphysics

P. K. Patra[1], S. K. Behera[1], J. R. Herman[2], S. Maksyutov[1], H. Akimoto[1], and T. Yamagata[3,1]



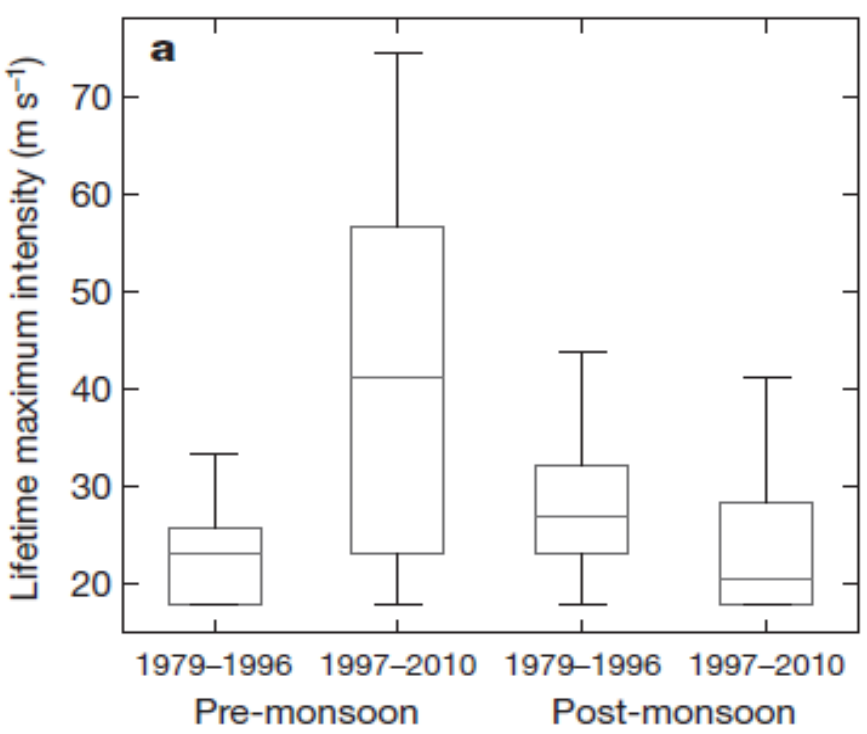
LETTER

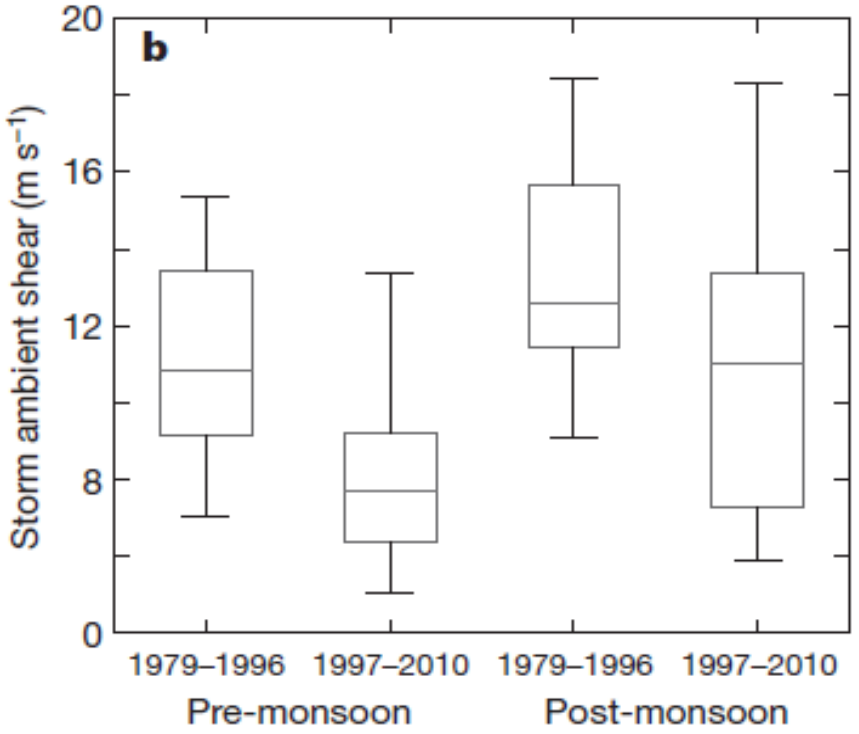
doi:10.1038/nature10552

Arabian Sea tropical cyclones intensified by emissions of black carbon and other aerosols

Amato T. Evan[1], James P. Kossin[2,3], Chul 'Eddy' Chung[4] & V. Ramanathan[5]

Nature, 2011



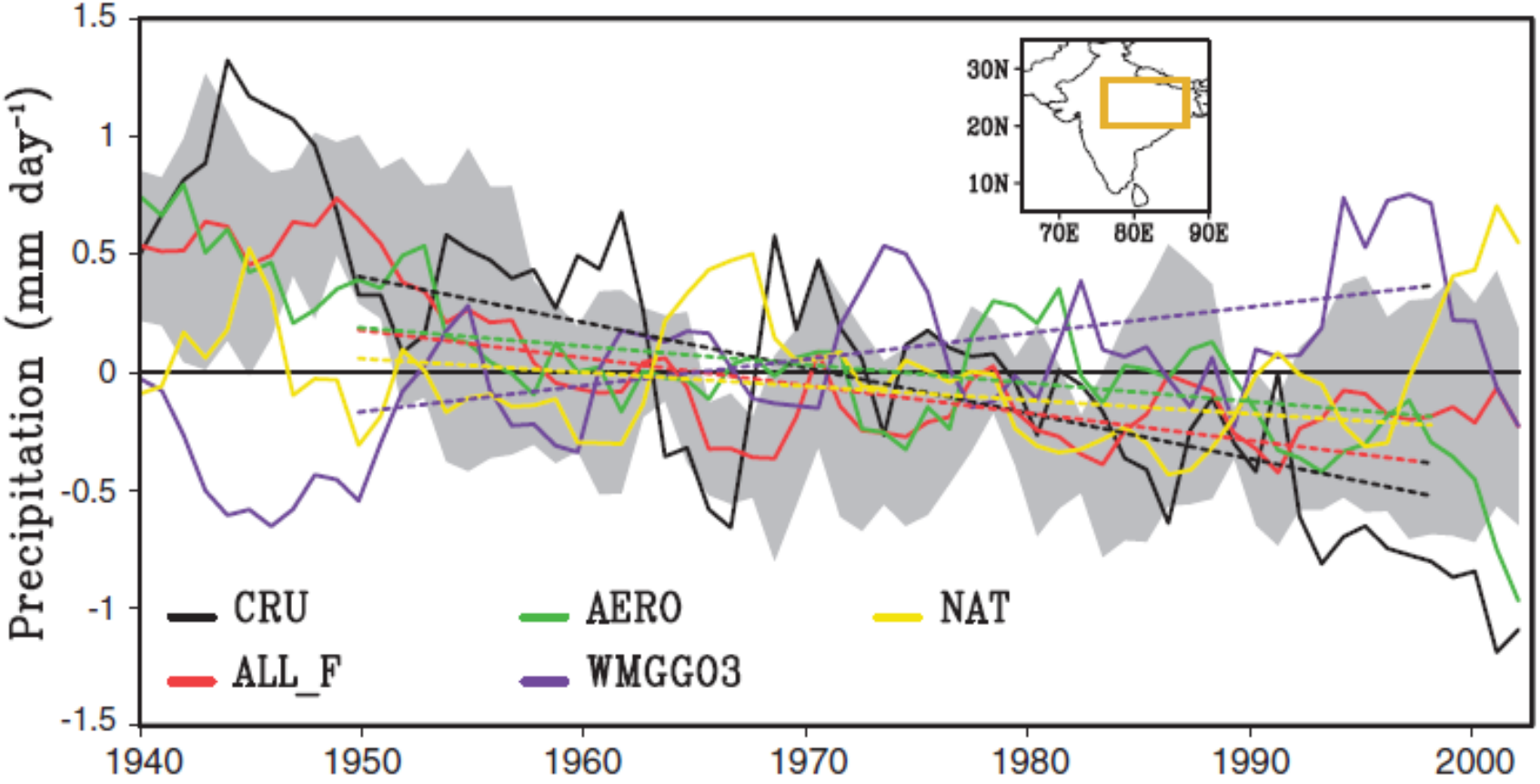


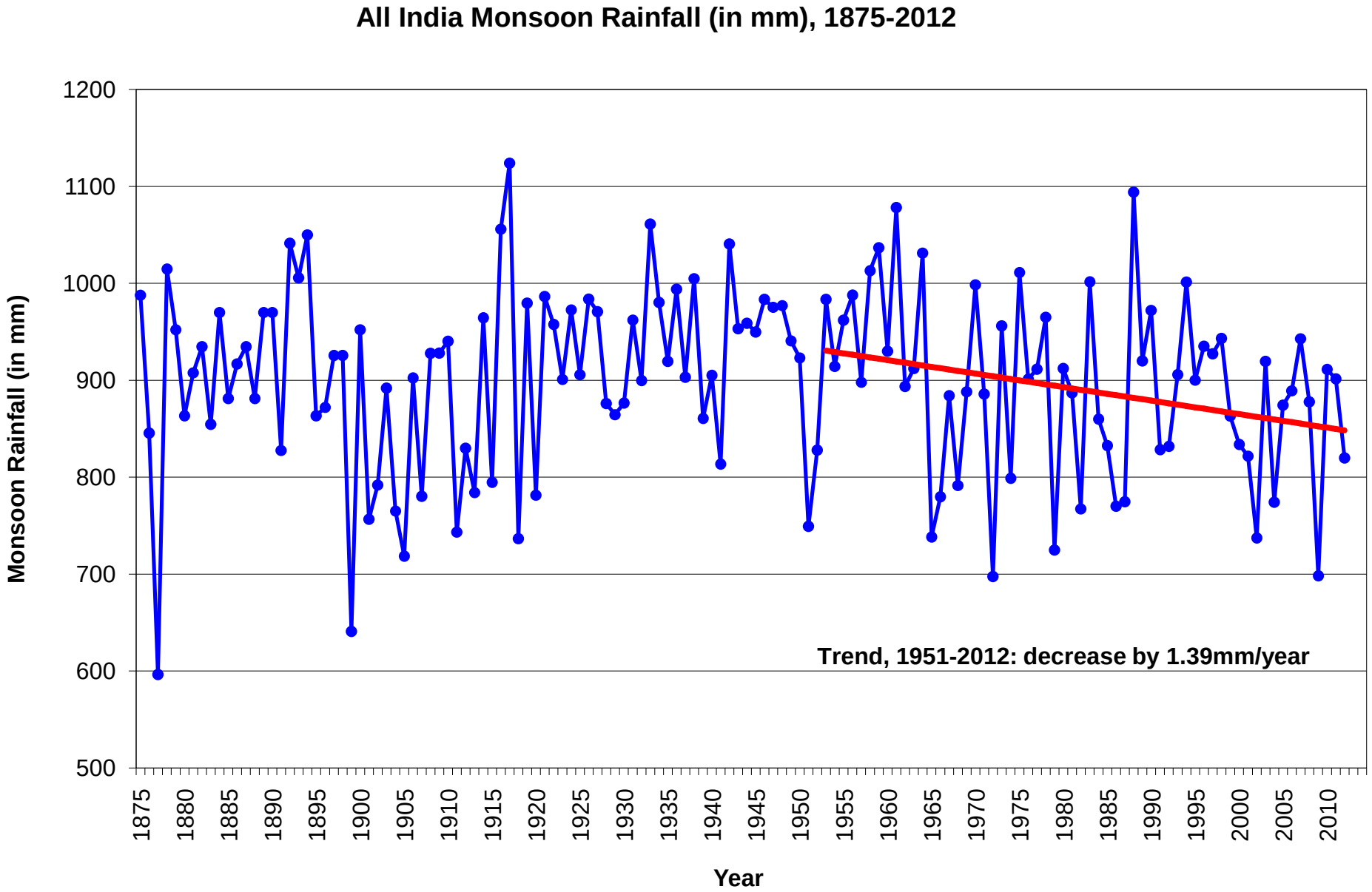
Monsoon circulation and rainfall trends

Anthropogenic Aerosols and the Weakening of the South Asian Summer Monsoon

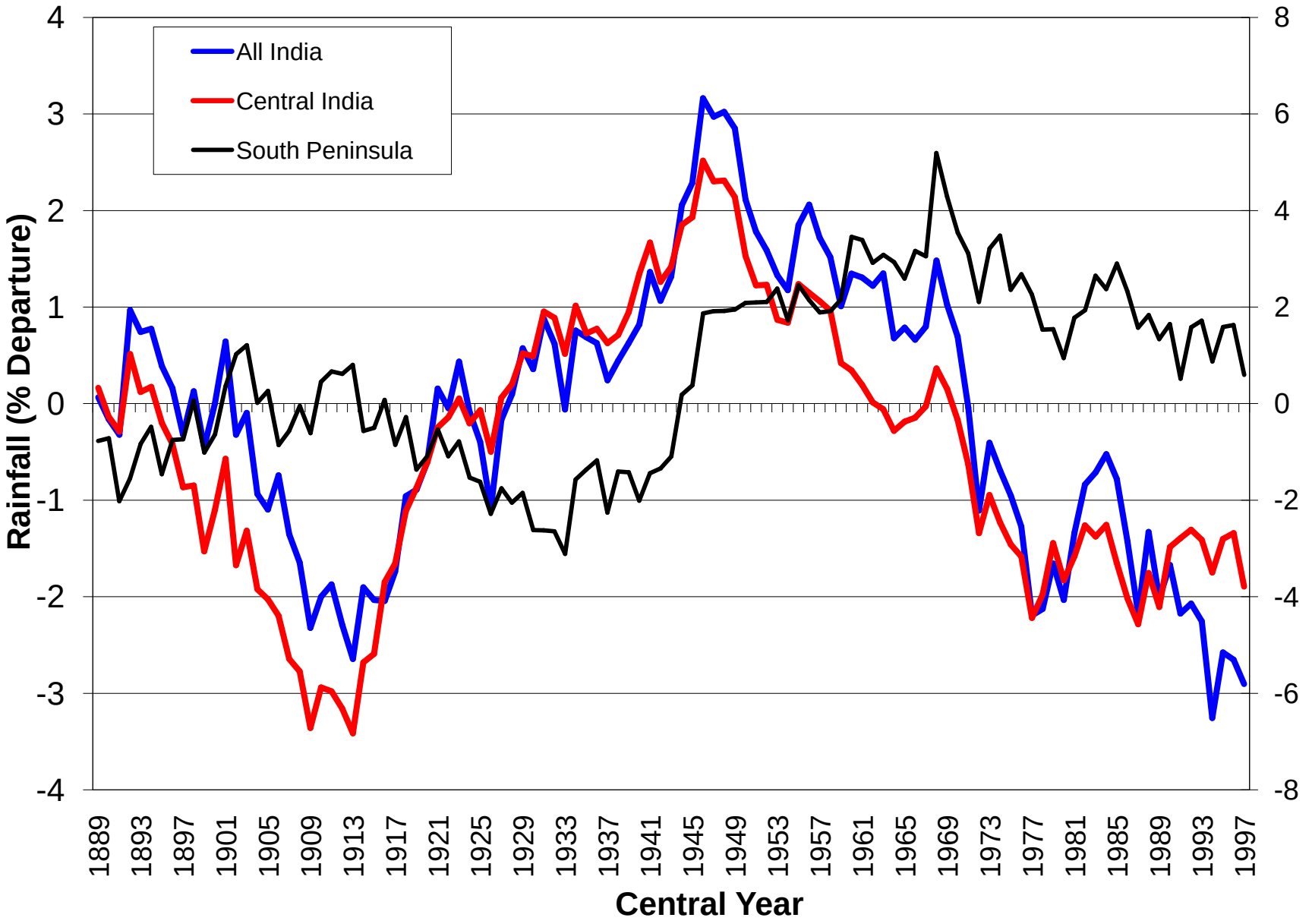
Massimo A. Bollasina,[1] Yi Ming,[2]* V. Ramaswamy[2]

Science, 2011

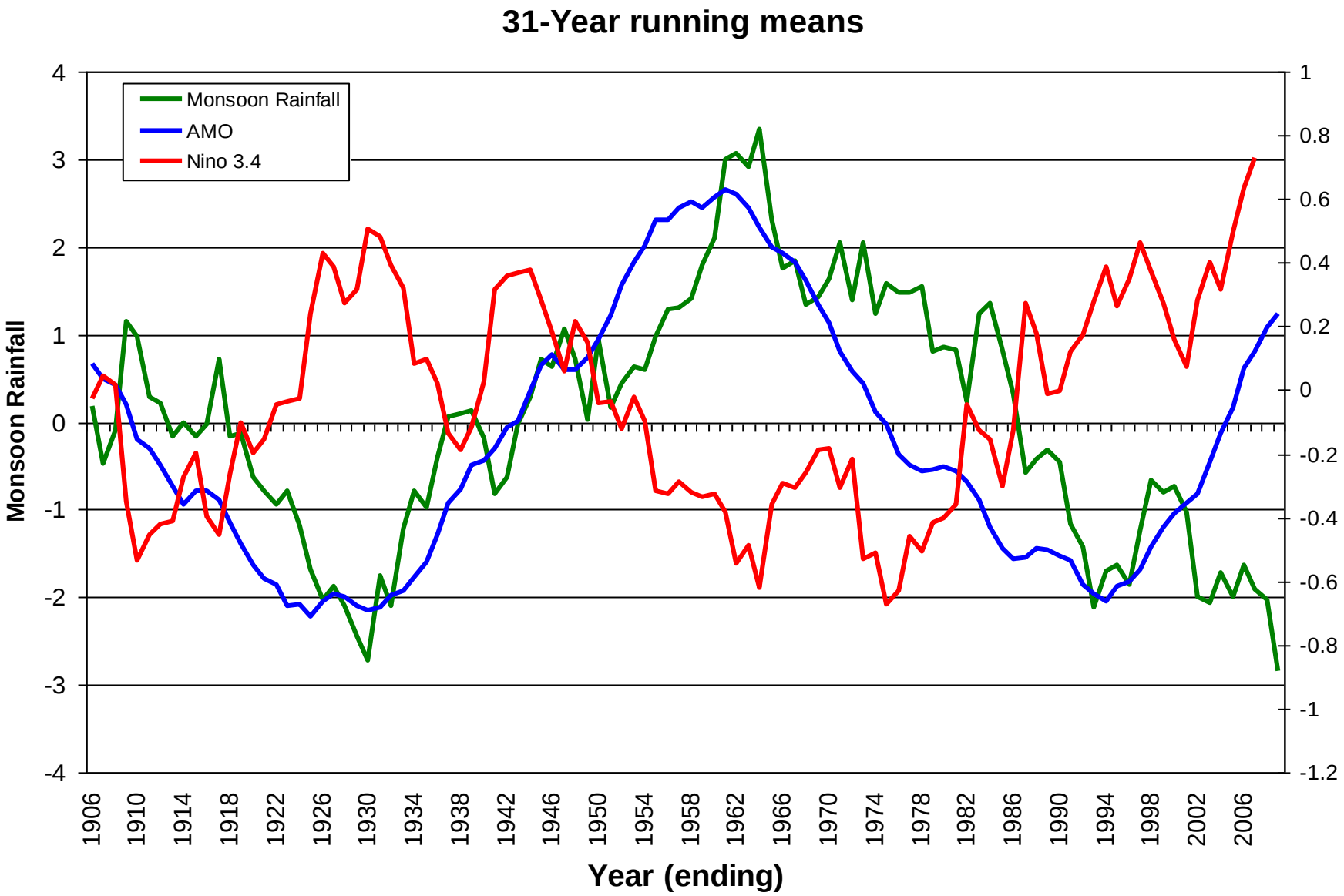


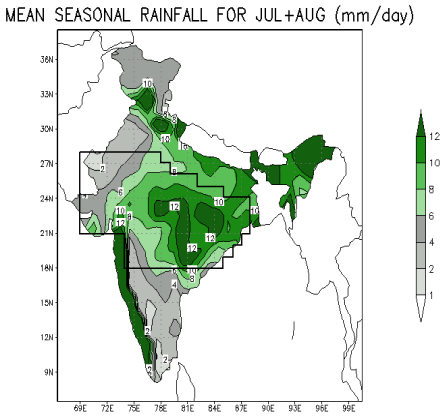


If we consider rainfall from 1951-2012, then there is a statistically significant decrease of all-India rainfall


31-Year Moving Average of ISMR
All India
Central India
South Peninsula
Rainfall (% Departure)
Central Year
4
3
2
1
0
-1
-2
-3
-4
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

Multi-decadal variations





Multi-decadal variations of ISMR and Break Days

ISMR (% Dep)

4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0

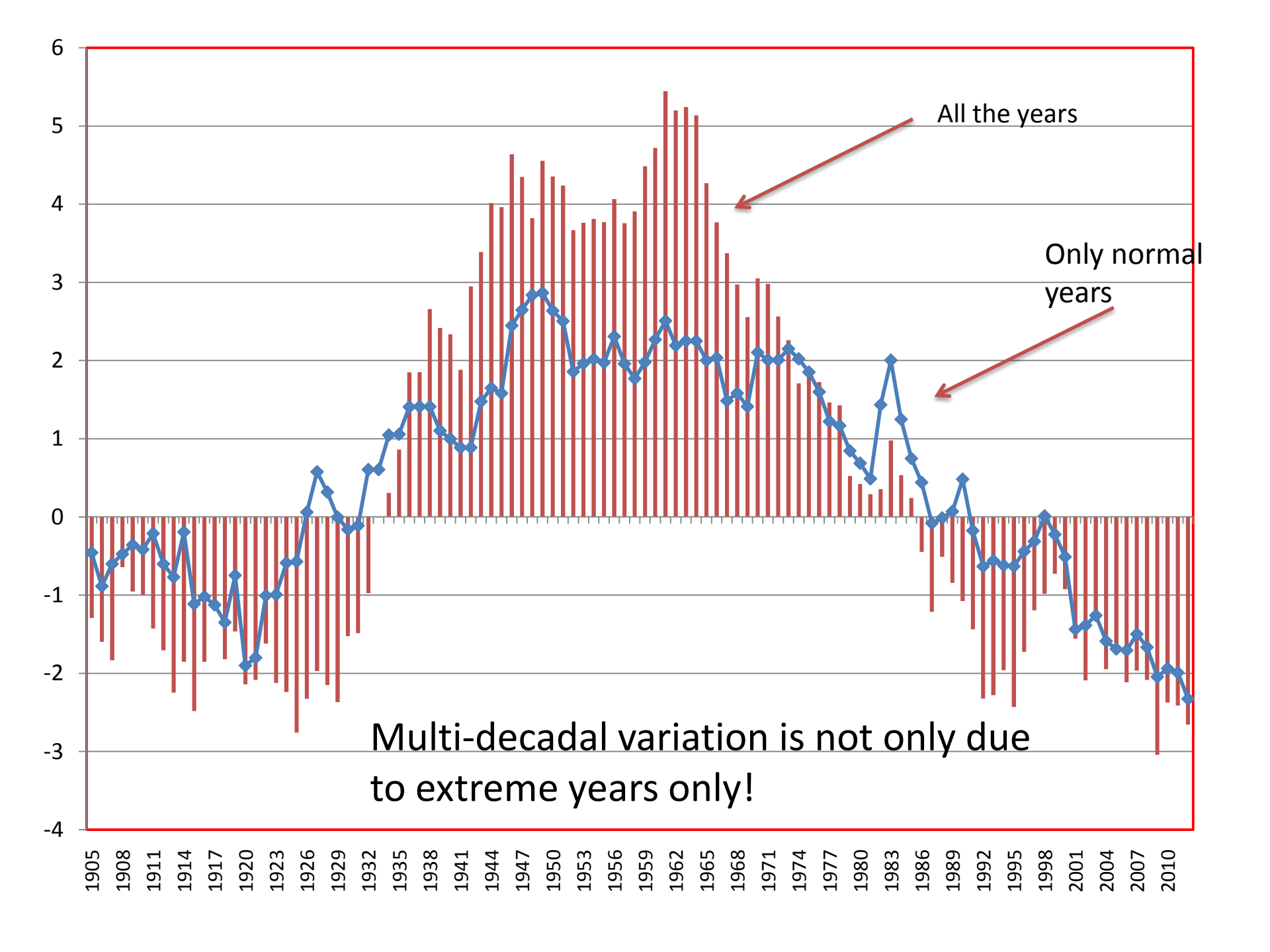
Break Days

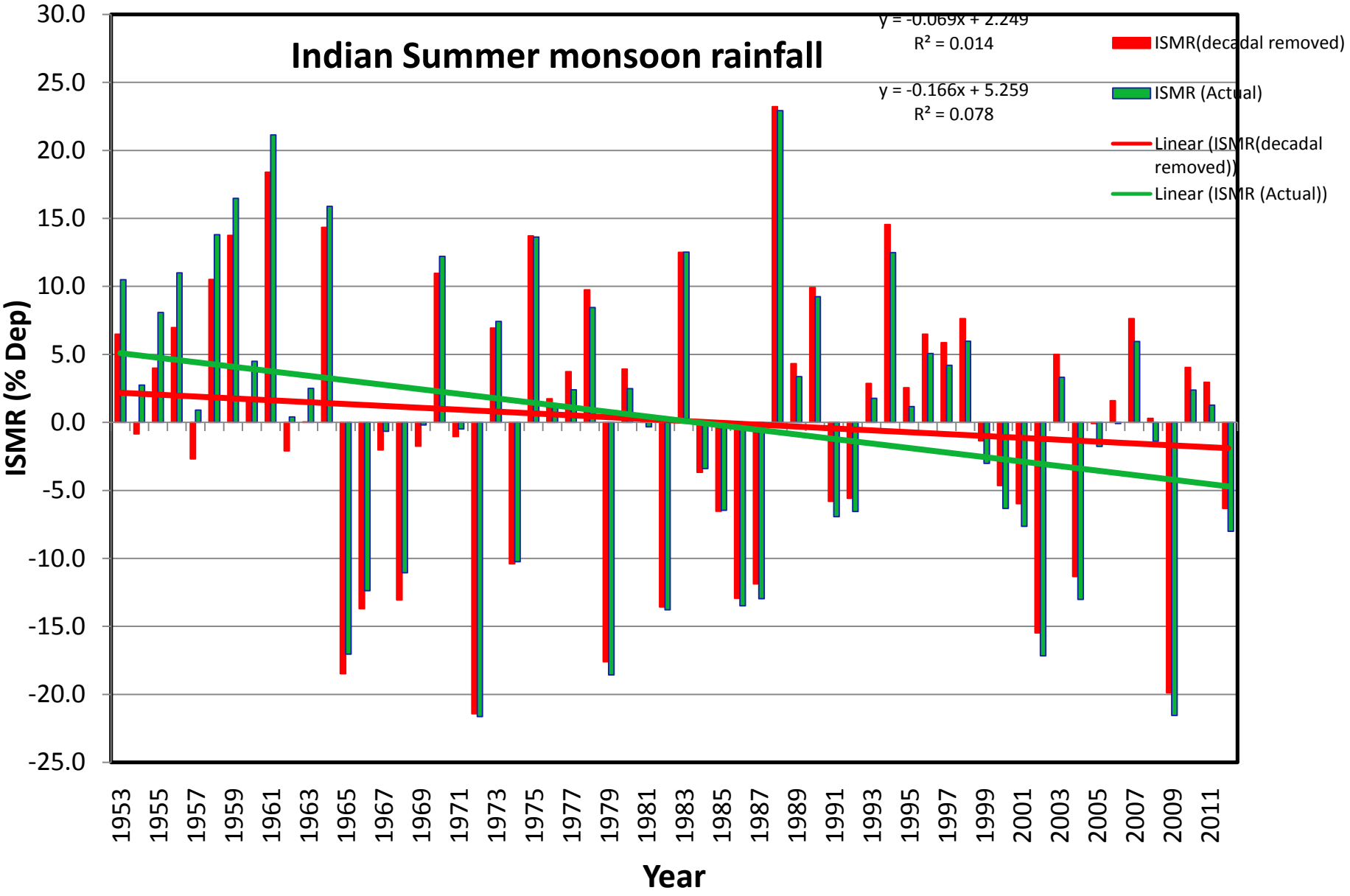
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0

ISMR
Break Days

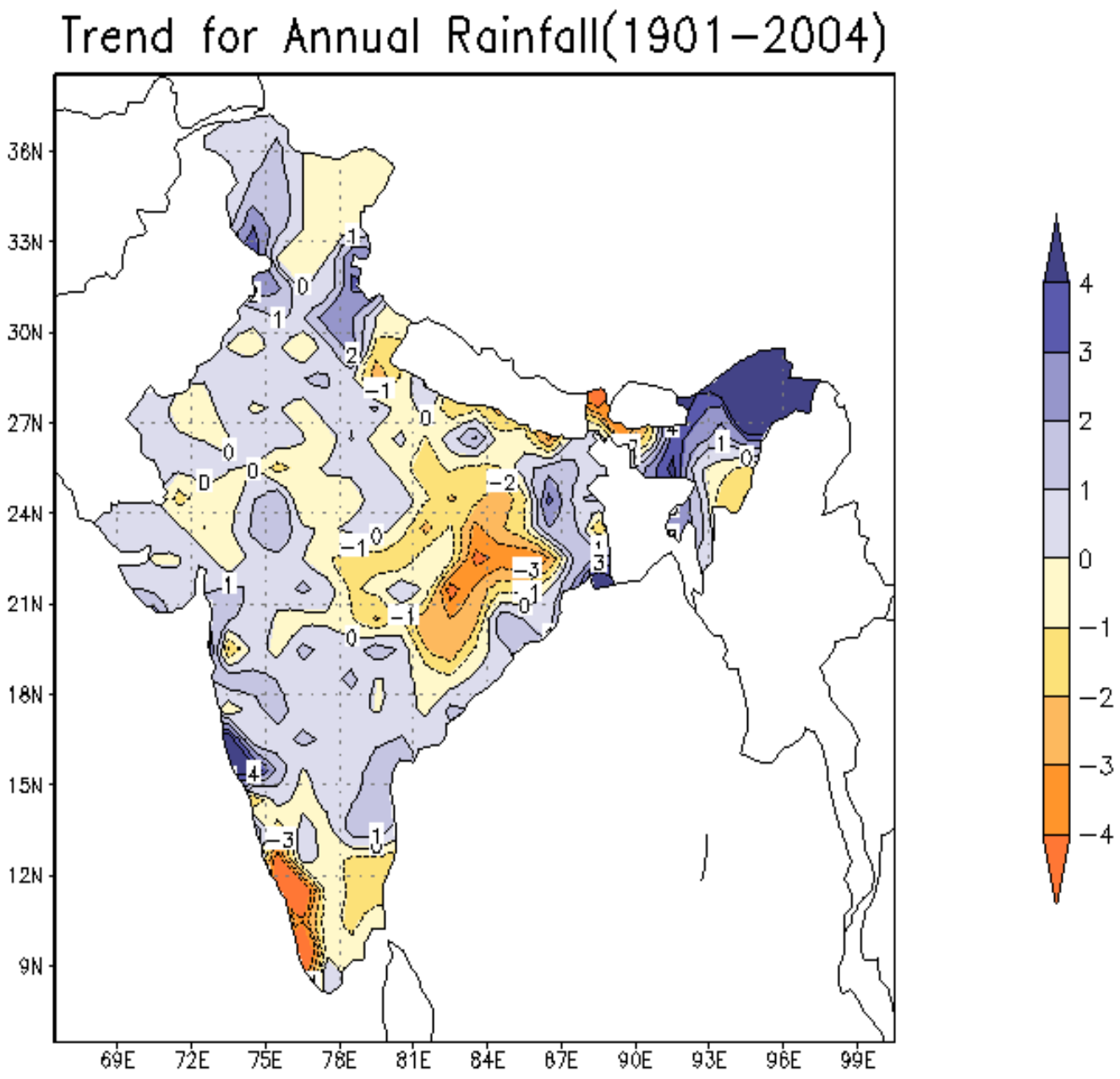
1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012

Year

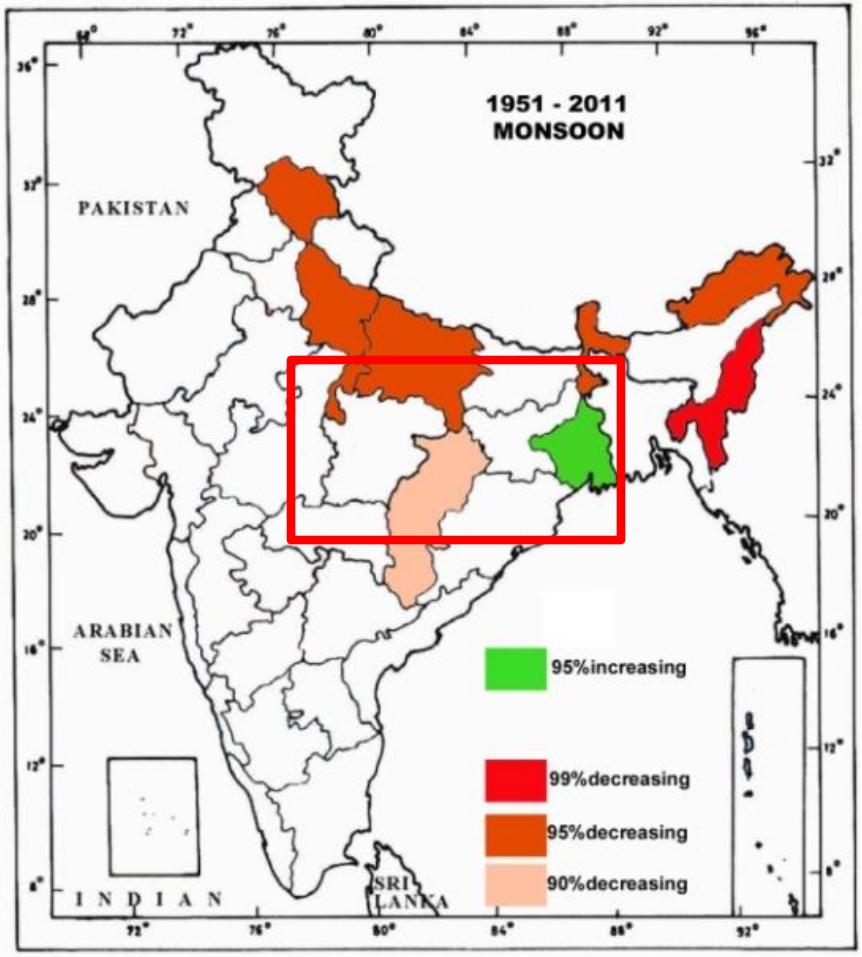

All the years
Only normal years
Multi-decadal variation is not only due to extreme years only!
6
5
4
3
2
1
0
-1
-2
-3
-4
1905
1908
1911
1914
1917
1920
1923
1926
1929
1932
1935
1938
1941
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010

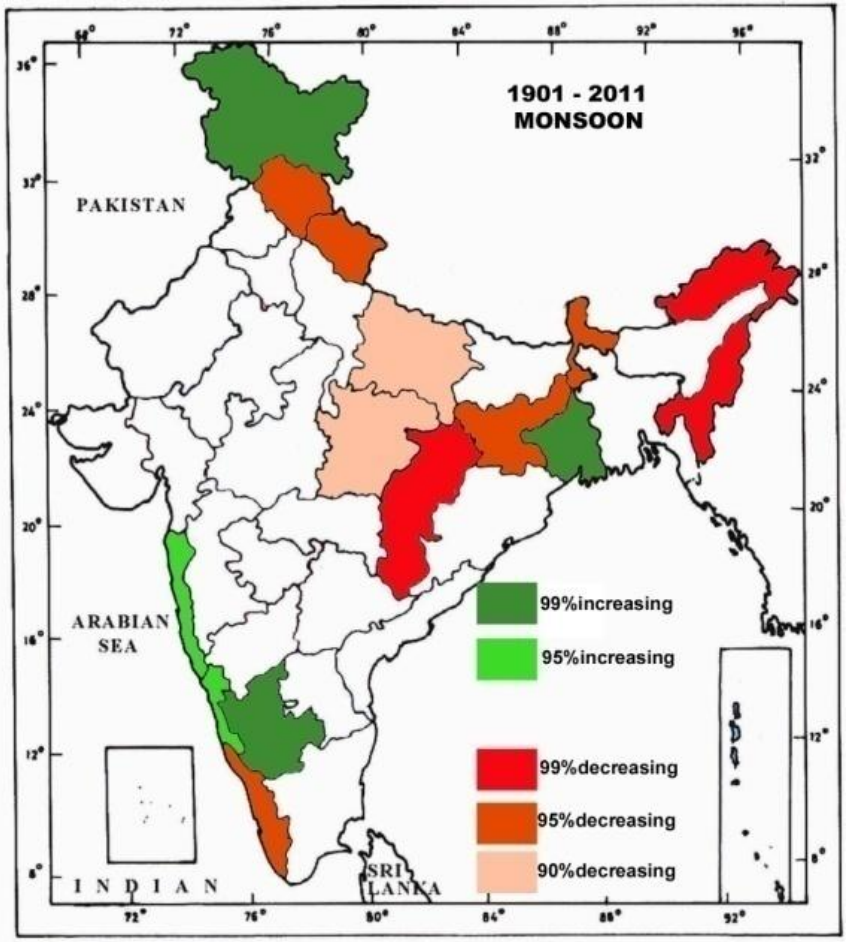


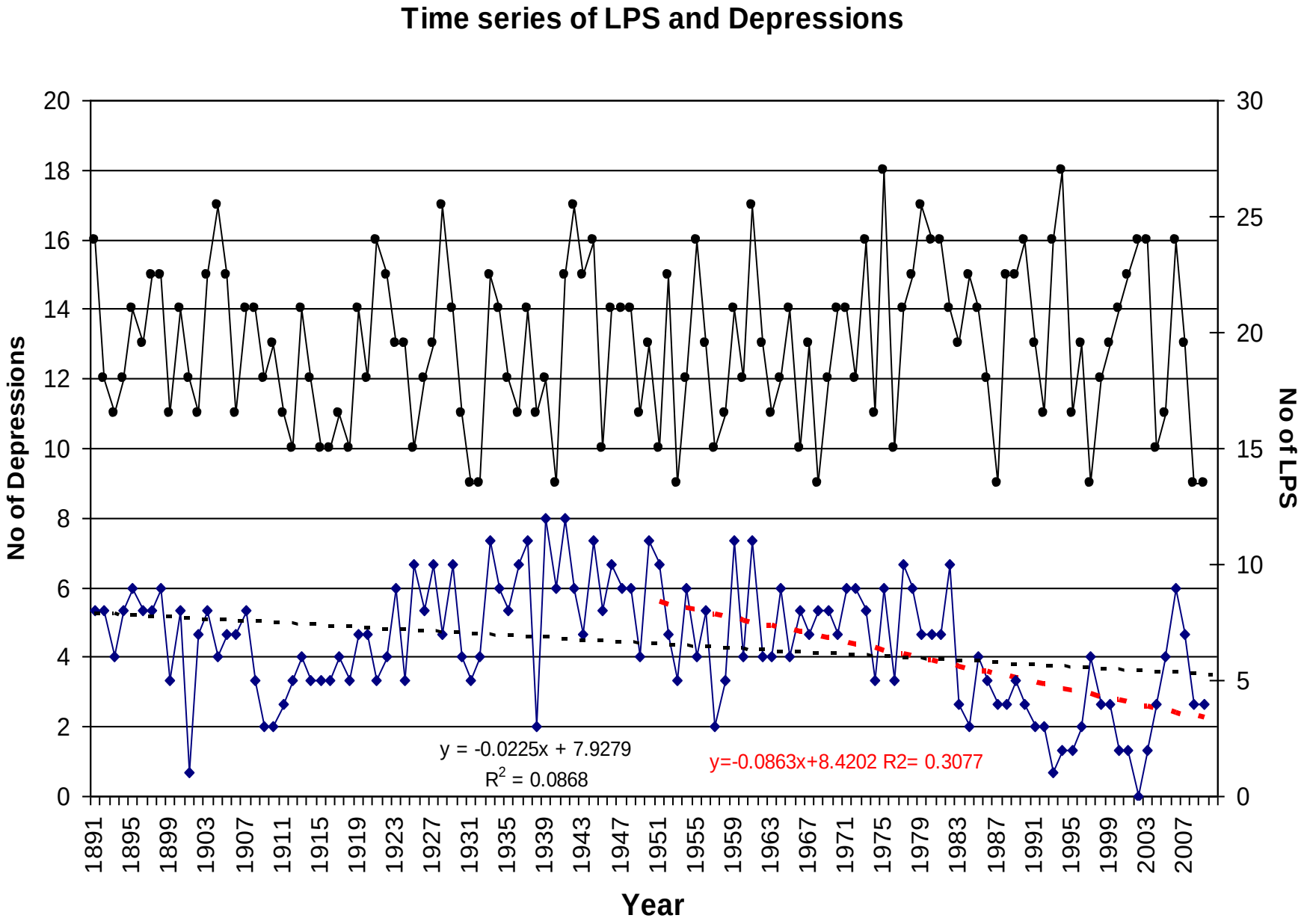
If we remove the significant multi-decadal variations of ISMR, then the trend from 1951-2012 becomes statistically insignificant

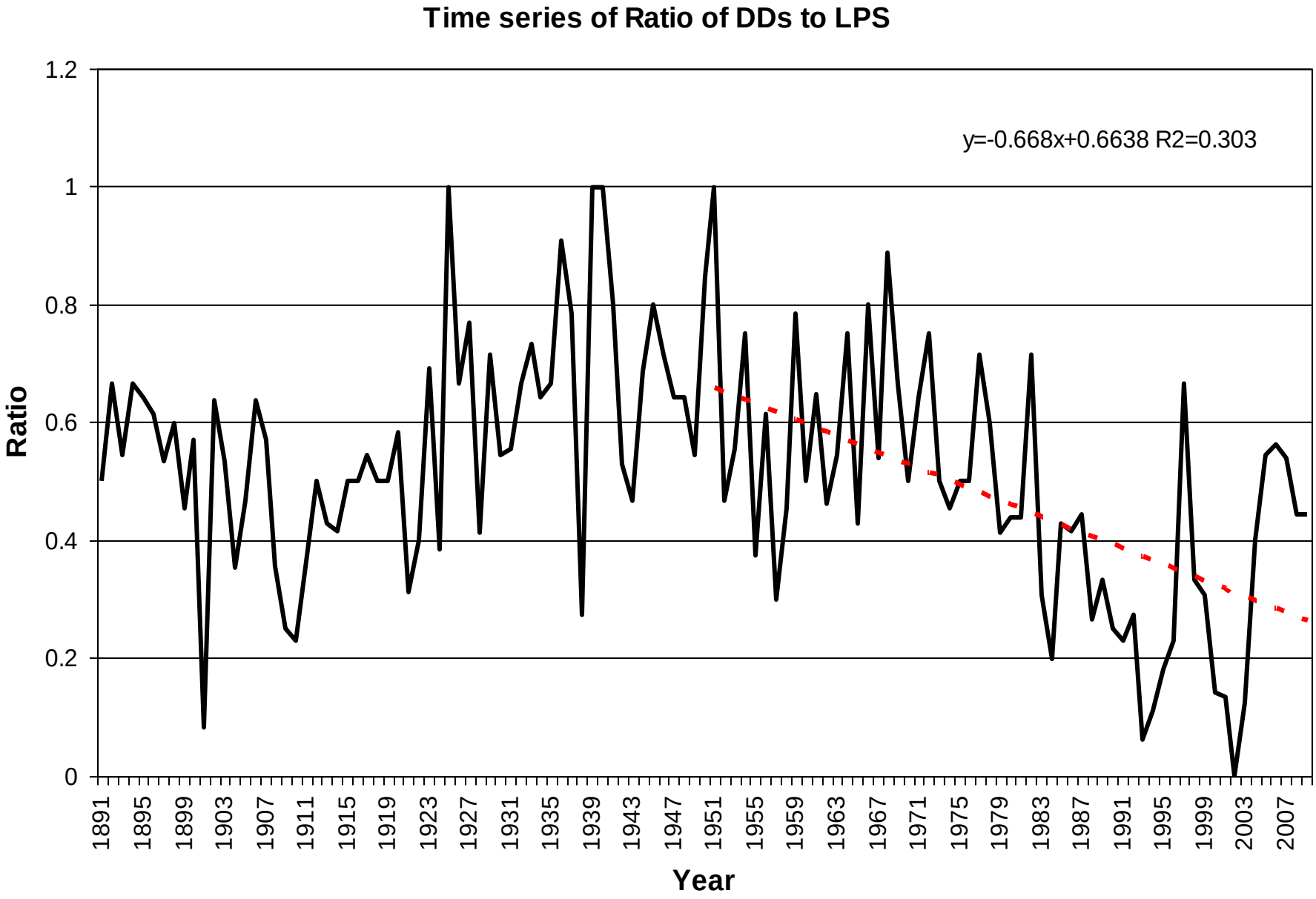

Trend for Annual Rainfall(1901–2004)
36N
33N
30N
27N
24N
21N
18N
15N
12N
9N
69E
72E
75E
78E
81E
84E
87E
90E
93E
96E
99E
4
3
2
1
0
−1
−2
−3
−4

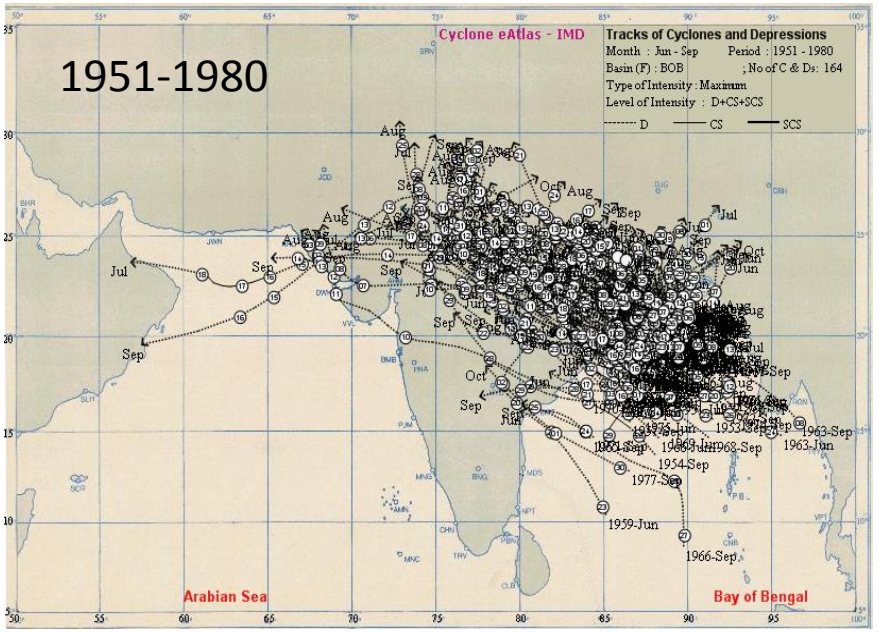
Regional monsoon rainfall

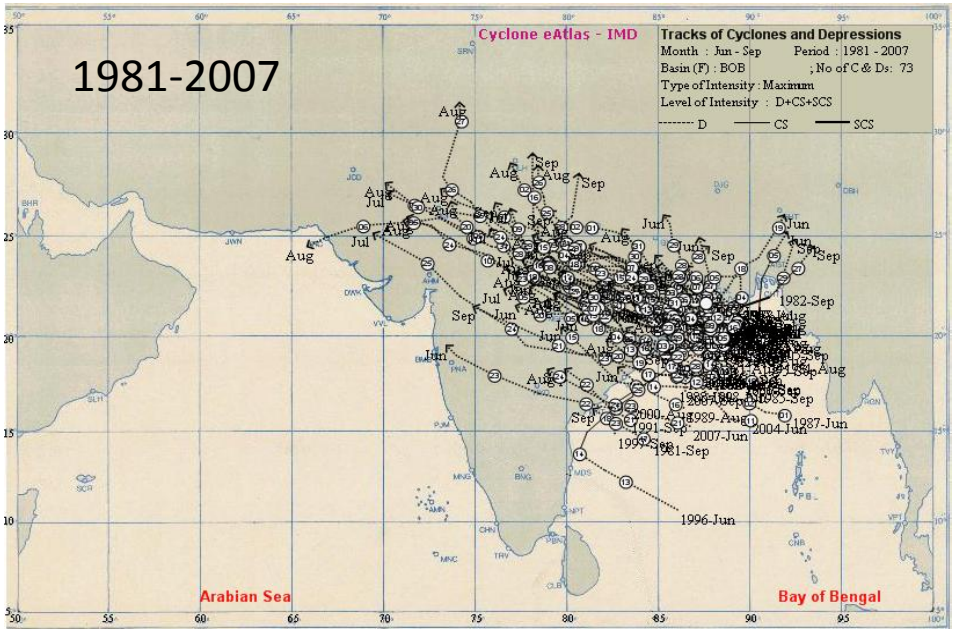


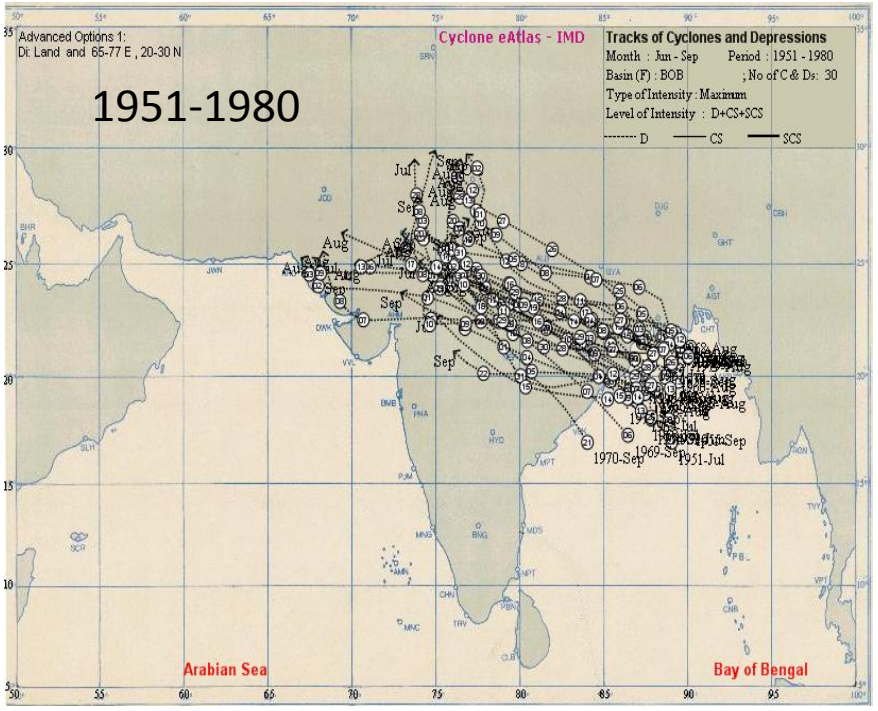


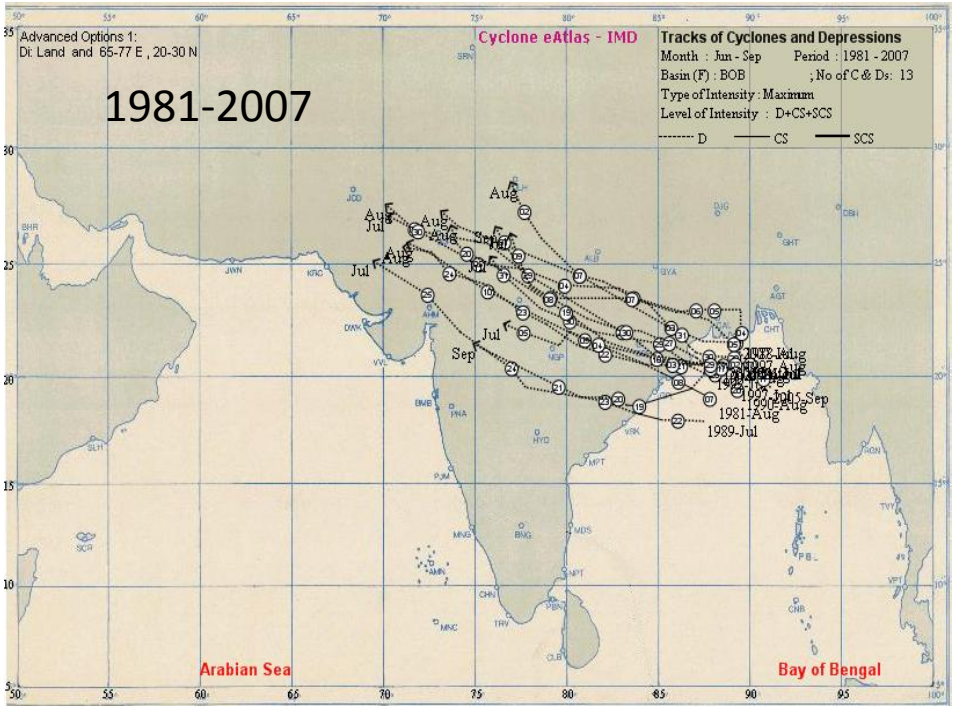

Time series of LPS and Depressions
No of Depressions
No of LPS
Year
y = -0.0225x + 7.9279
R2 = 0.0868
y=-0.0863x+8.4202 R2= 0.3077


Time series of Ratio of DDs to LPS
y=-0.668x+0.6638 R2=0.303
Ratio
Year
1.2
1
0.8
0.6
0.4
0.2
0
1891
1895
1899
1903
1907
1911
1915
1919
1923
1927
1931
1935
1939
1943
1947
1951
1955
1959
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007


1951-1980
Cyclone eAtlas - IMD
Tracks of Cyclones and Depressions
Month : Jun - Sep Period : 1951 - 1980
Basin (F) : BOB ; No of C & Ds: 164
Type of Intensity : Maximum
Level of Intensity : D+CS+SCS
D CS SCS
Arabian Sea
Bay of Bengal


1981-2007
Cyclone eAtlas - IMD
Tracks of Cyclones and Depressions
Month : Jun - Sep Period : 1981 - 2007
Basin (F) : BOB ; No of C & Ds: 73
Type of Intensity : Maximum
Level of Intensity : D+CS+SCS
D CS SCS
1996-Jun
Arabian Sea
Bay of Bengal


Advanced Options 1:
Dt: Land and 65-77 E , 20-30 N
1951-1980
Cyclone eAtlas - IMD
Tracks of Cyclones and Depressions
Month : Jun - Sep Period : 1951 - 1980
Basin (F) : BOB ; No of C & Ds: 30
Type of Intensity : Maximum
Level of Intensity : D+CS+SCS
D CS SCS
1970-Sep
1969-Sep
1951-Jul
Arabian Sea
Bay of Bengal


Advanced Options 1:
Dt: Land and 65-77 E , 20-30 N
1981-2007
Cyclone eAtlas - IMD
Tracks of Cyclones and Depressions
Month : Jun - Sep Period : 1981 - 2007
Basin (F) : BOB ; No of C & Ds: 13
Type of Intensity : Maximum
Level of Intensity : D+CS+SCS
D CS SCS
1989-Jul
Arabian Sea
Bay of Bengal

Impacts of enhanced CCN on the organization of convection and recent reduced counts of monsoon depressions

T. N. Krishnamurti ; Andrew Martin ; Ruby Krishnamurti ; Anu Simon ; Aype Thomas ; Vinay Kumar

Proc. SPIE 8529, Remote Sensing and Modeling of the Atmosphere, Oceans, and Interactions IV, 85290E (November 29, 2012); doi:10.1117/12.979717

•This paper addresses the effects of pollution for the enhancement of cloud condensation nuclei and the resulting disruption of the organization of convection in monsoon depressions. Our specific studies make use of a high resolution mesoscale model (WRF/CHEM) to explore the impacts of the first and second aerosol indirect effects proposed by Twomey and Albrecht.

We have conducted preliminary studies including examination of the evolution of radar reflectivity (computed inversely from the model hydrometeors) for normal and enhanced CCN effects (arising from enhanced monsoon pollution).

The time lapse histories show a major disruption in the organization of convection of the monsoon depressions on the time scale of a week to ten days in these enhanced CCN scenarios.

Vertical wind shear/ horizontal wind shear

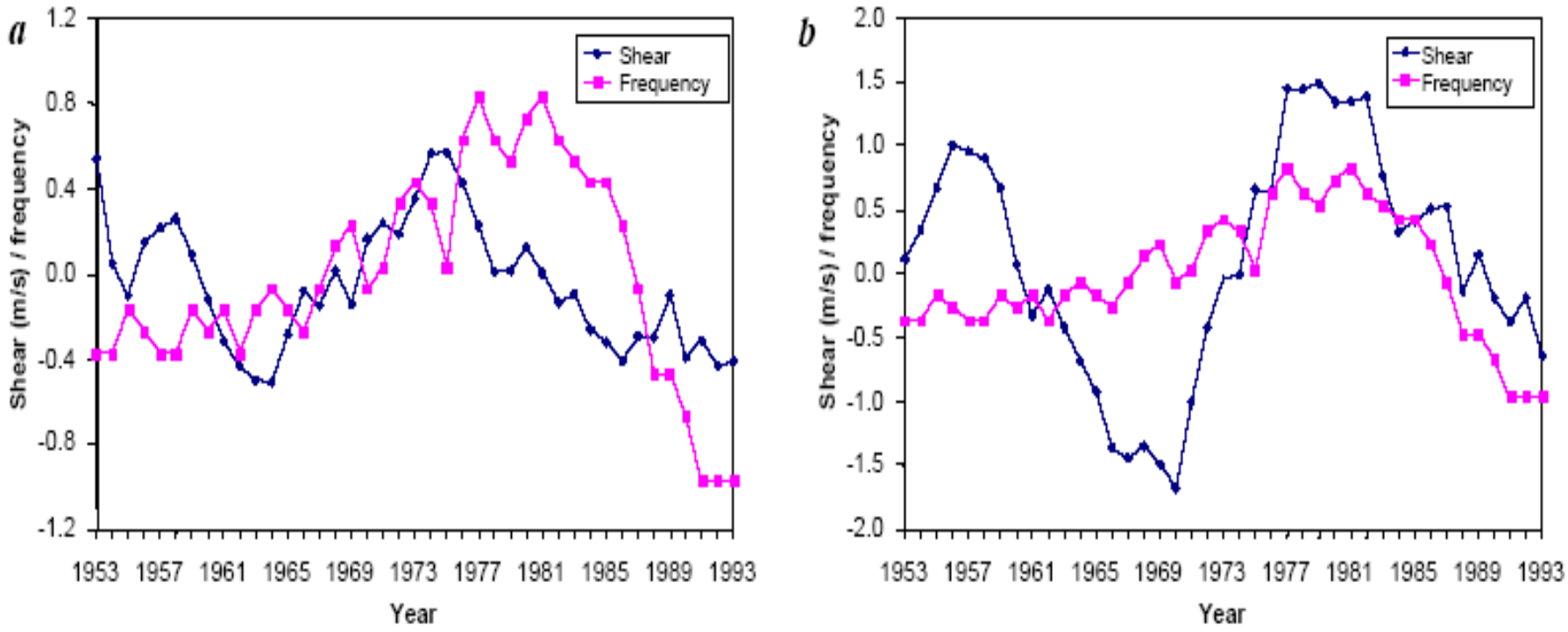
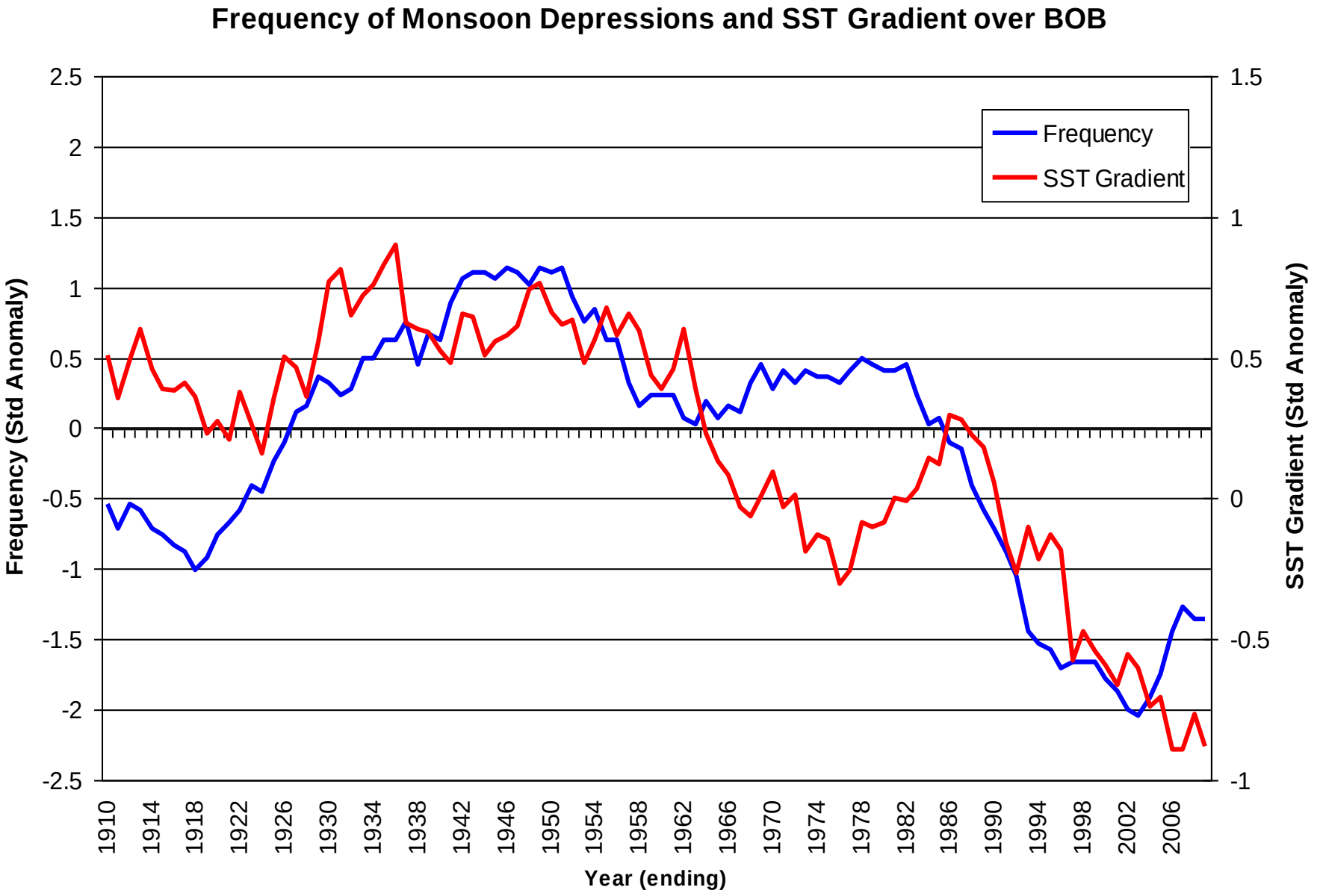
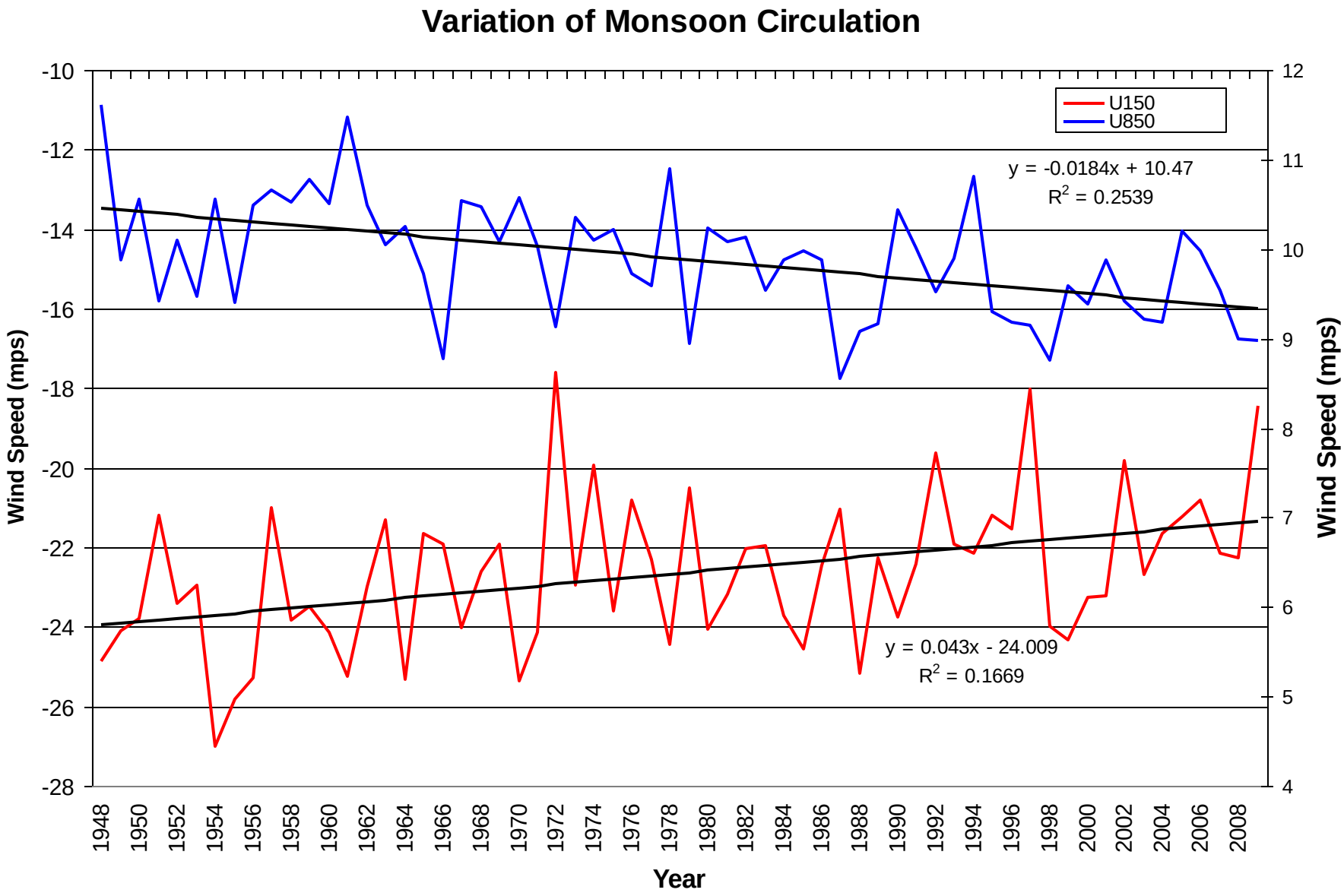


Figure 5. *a*, Same as in Figure 4 *a*, but for the month of August. *b*, Same as in Figure 4 *b*, but for the month of August.

It is speculated that the decrease in frequency of monsoon depressions is due to decrease in horizontal and vertical wind shears

Dash et al, Current Science, 2004


Frequency of Monsoon Depressions and SST Gradient over BOB
Frequency
SST Gradient
Frequency (Std Anomaly)
SST Gradient (Std Anomaly)
Year (ending)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1.5
1
0.5
0
-0.5
-1
1910
1914
1918
1922
1926
1930
1934
1938
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006


Variation of Monsoon Circulation
U150
U850
y = -0.0184x + 10.47
R2 = 0.2539
y = 0.043x - 24.009
R2 = 0.1669
Wind Speed (mps)
Wind Speed (mps)
Year
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
12
11
10
9
8
7
6
5
4
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008

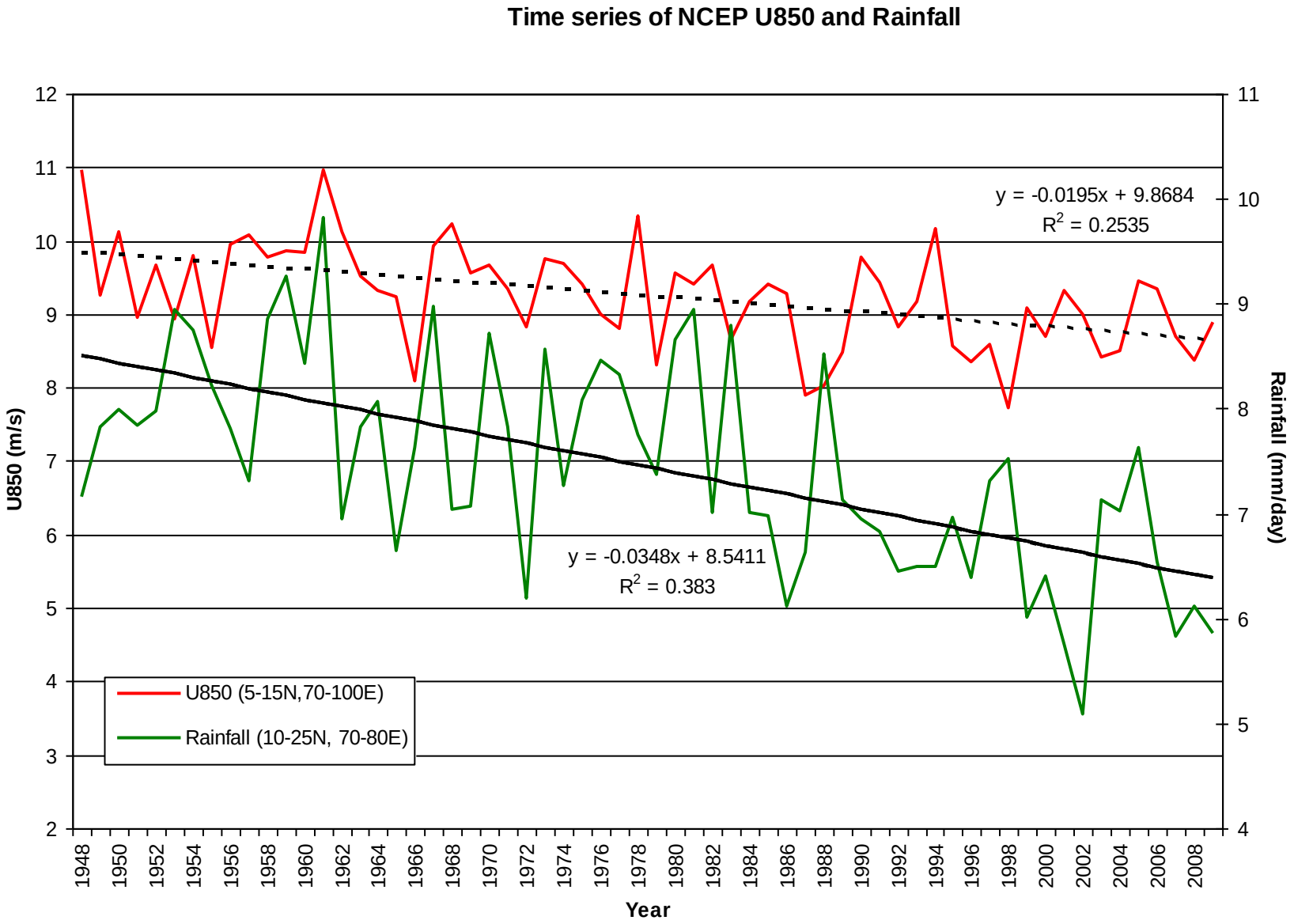
Reanalysis and climate trends: IPCC AR4

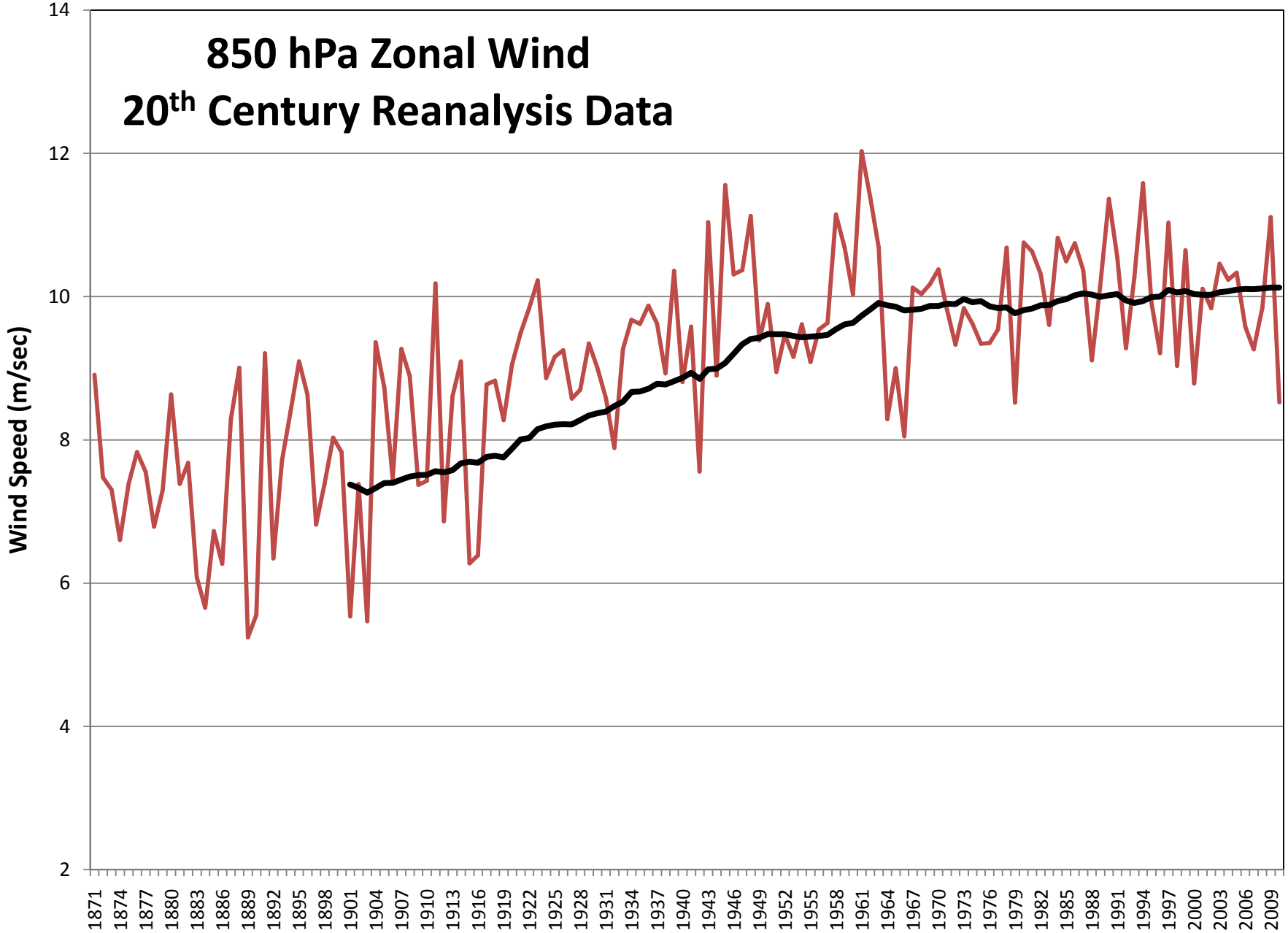
Chapter-3

Supplement material: Page 8

"In reality, however, observational coverage varies over time, observations are themselves prone to bias, either instrumental or through not being representative of their wider surrounding, and these observational biases can change over time. This introduces trends and low-frequency variations in analyses that are mixed with the true climatic signals, making long timescale trends over the full length of the reanalyses potentially unreliable. Better representation of trends by reanalysis systems requires progress on identifying and correcting model and observational biases, assimilating as complete as set of past observations as possible."

Reanalysis and climatic trends




850 hPa Zonal Wind
20th Century Reanalysis Data
Wind Speed (m/sec)
14
12
10
8
6
4
2
1871
1874
1877
1880
1883
1886
1889
1892
1895
1898
1901
1904
1907
1910
1913
1916
1919
1922
1925
1928
1931
1934
1937
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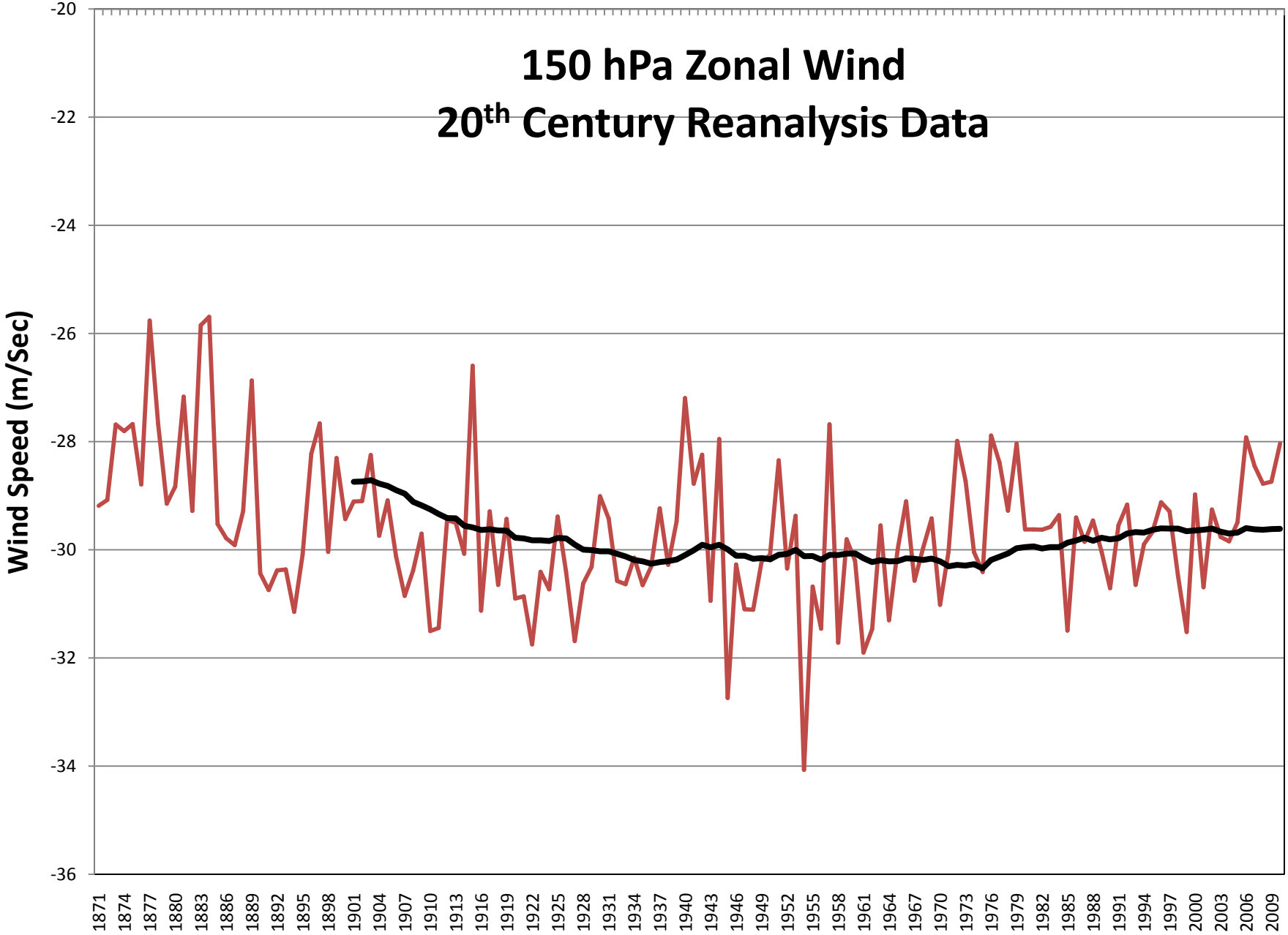
1997
2000
2003
2006
2009


150 hPa Zonal Wind
20th Century Reanalysis Data
Wind Speed (m/Sec)
-20
-22
-24
-26
-28
-30
-32
-34
-36
1871
1874
1877
1880
1883
1886
1889
1892
1895
1898
1901
1904
1907
1910
1913
1916
1919
1922
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
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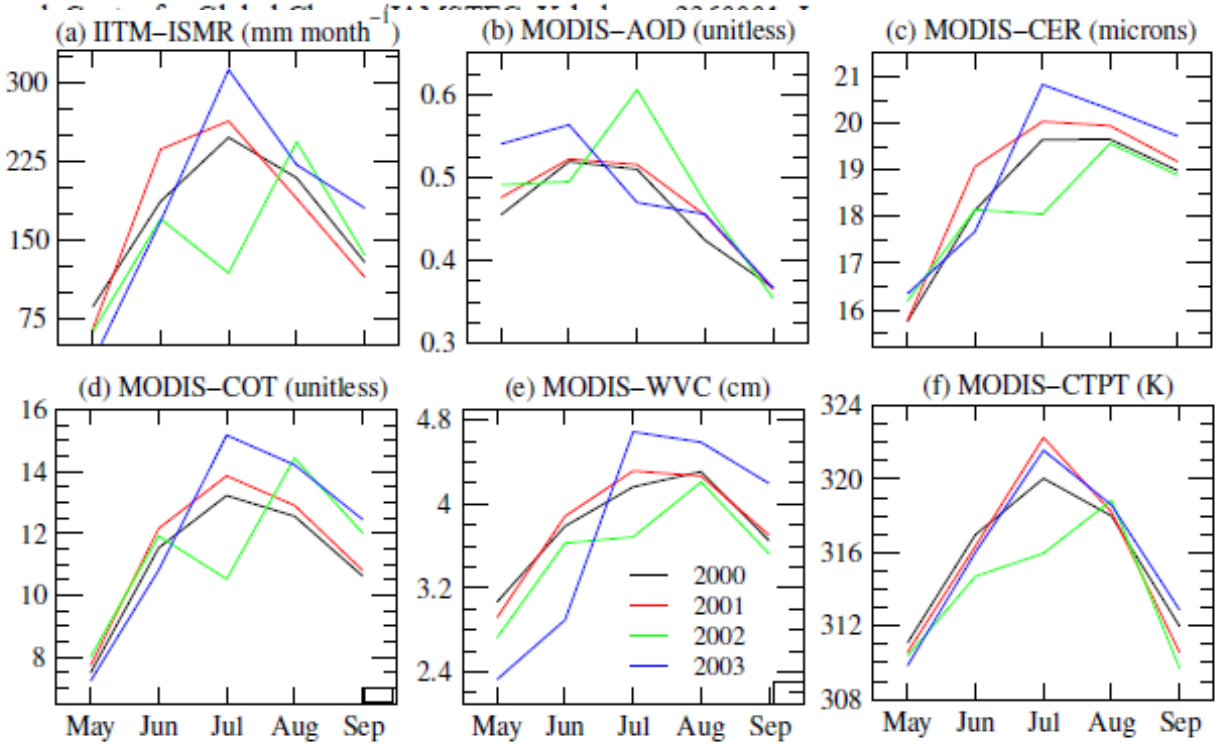
1988
1991
1994
1997
2000
2003
2006
2009

Atmos. Chem. Phys., 5, 2181–2188, 2005
www.atmos-chem-phys.org/acp/5/2181/
SRef-ID: 1680-7324/acp/2005-5-2181
European Geosciences Union

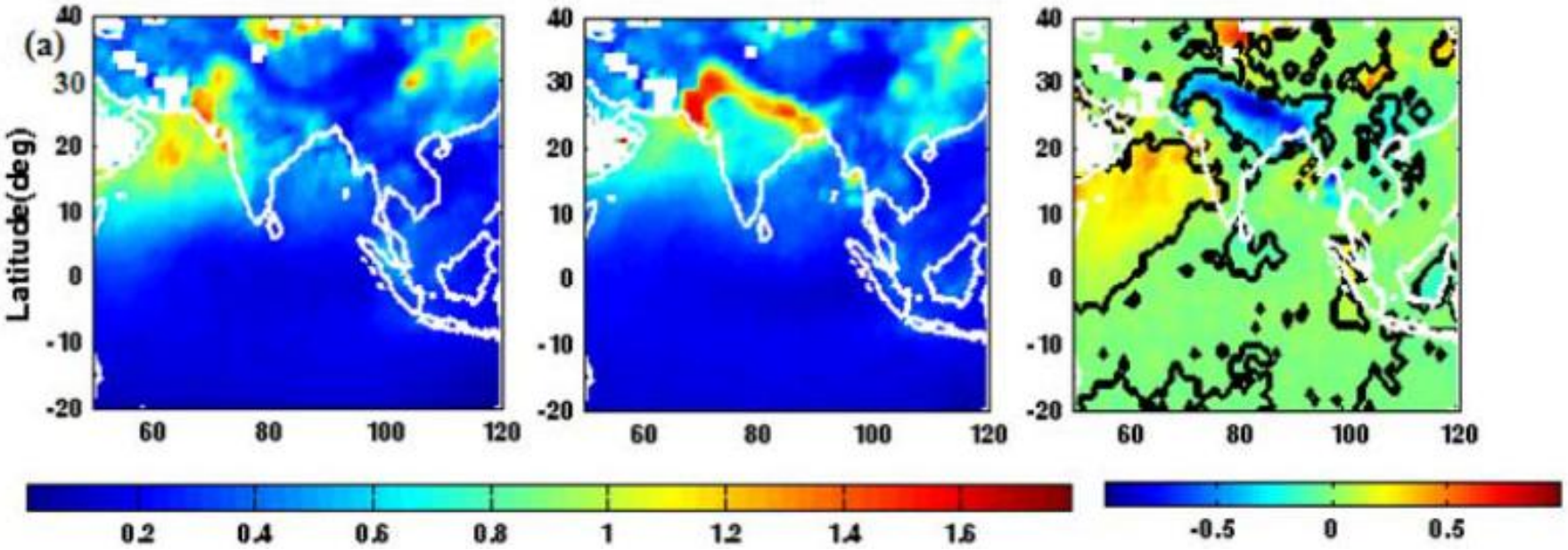
Atmospheric Chemistry and Physics

The Indian summer monsoon rainfall: interplay of coupled dynamics, radiation and cloud microphysics

P. K. Patra[1], S. K. Behera[1], J. R. Herman[2], S. Maksyutov[1], H. Akimoto[1], and T. Yamagata[3,1]



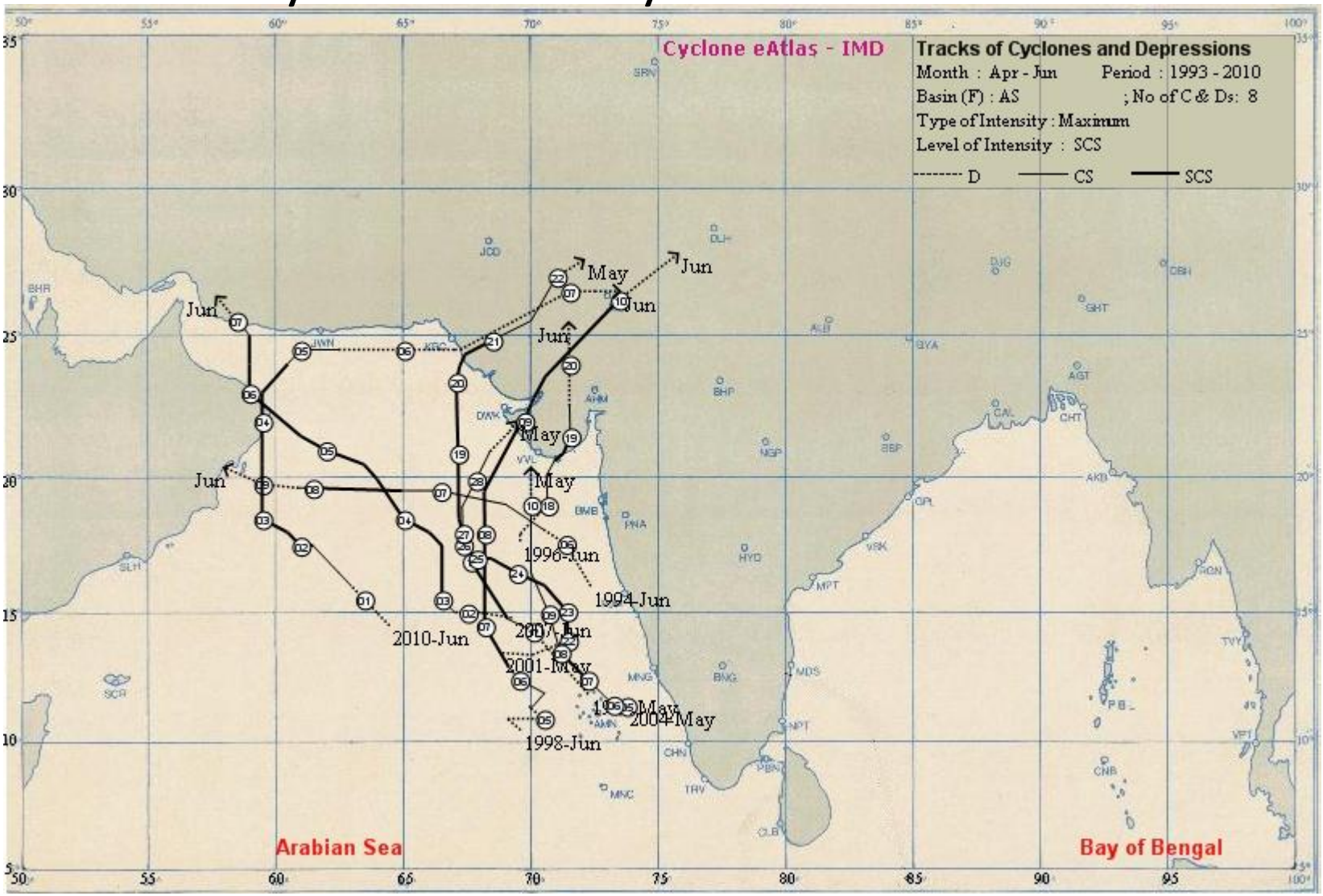
Aerosols and break monsoon



During the break monsoon periods, more aerosol loading is observed over central plains of India. This could be attributed to the circulation anomalies associated with the monsoon breaks

Ravi Kiran, M Rajeevan and S Vijaya Bhasakara Rao, 2009, Goephys. Res. Letters

Increase in Pre-monsoon Tropical Cyclone Intensity



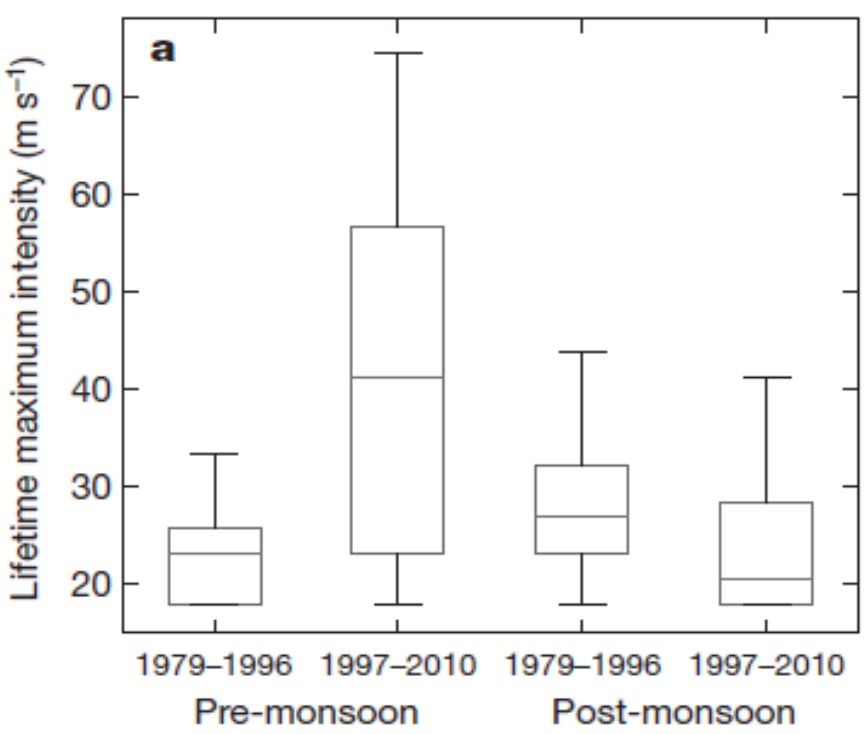
LETTER

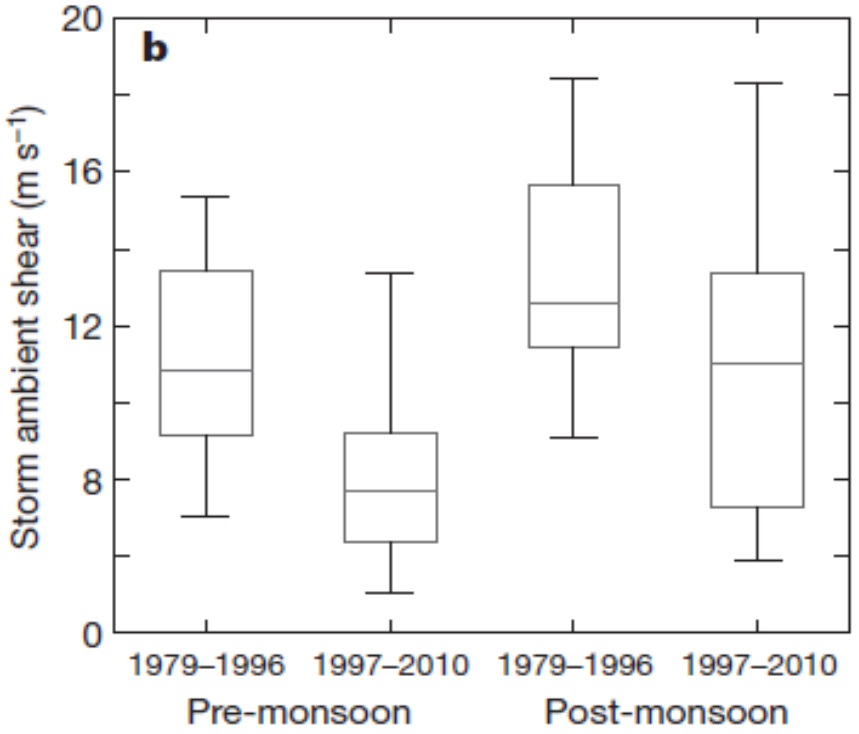
doi:10.1038/nature10552

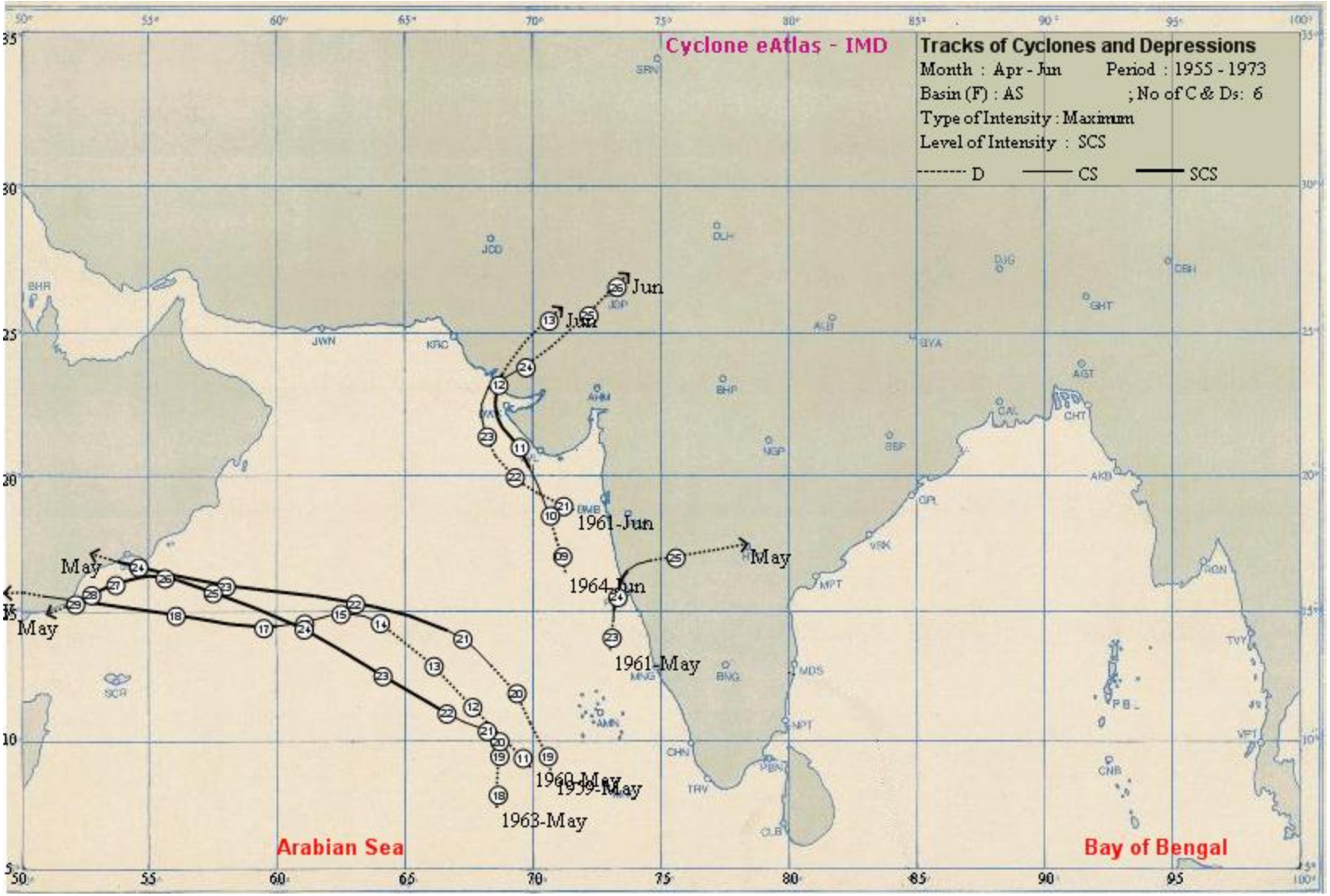
Arabian Sea tropical cyclones intensified by emissions of black carbon and other aerosols

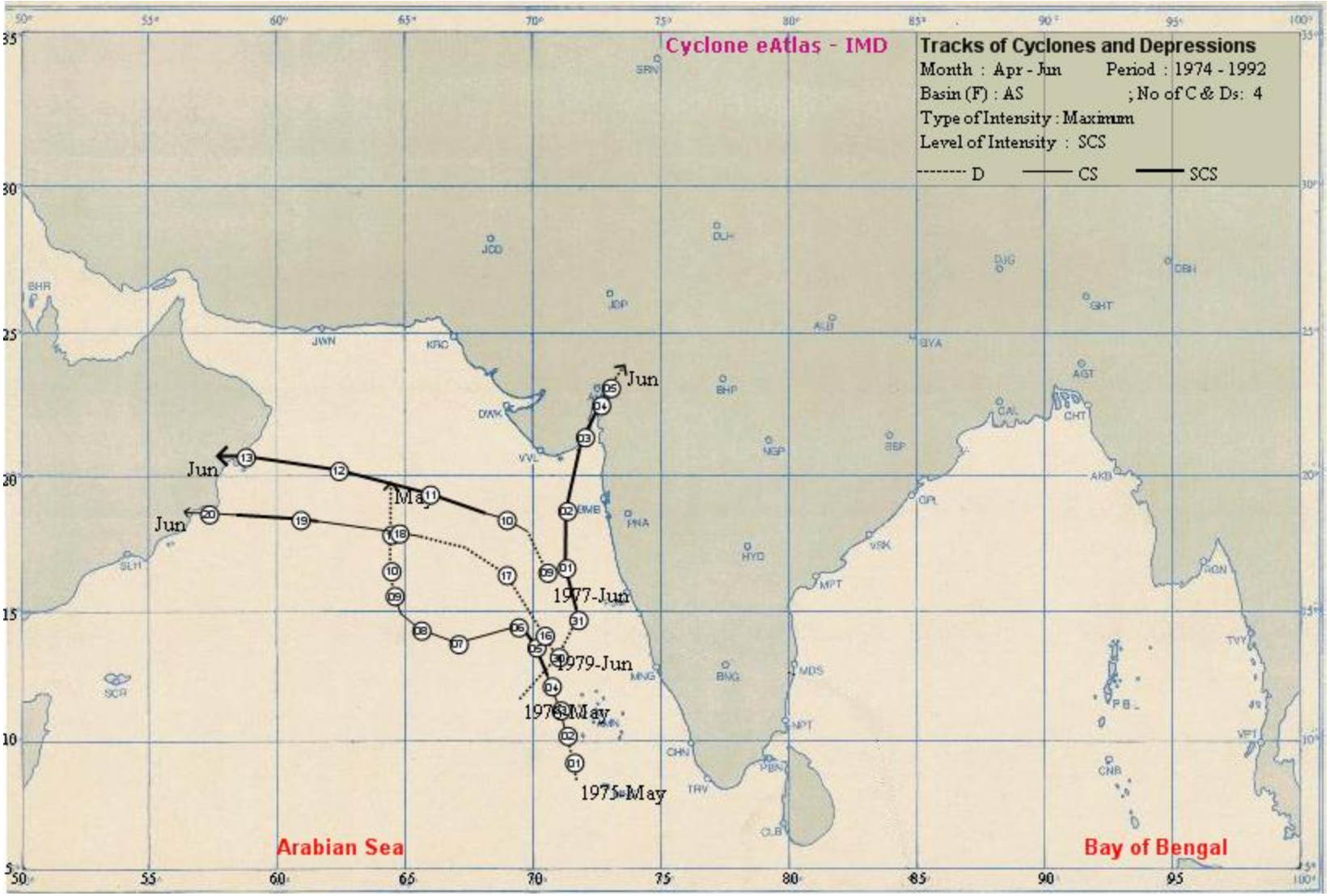
Amato T. Evan[1], James P. Kossin[2,3], Chul 'Eddy' Chung[4] & V. Ramanathan[5]

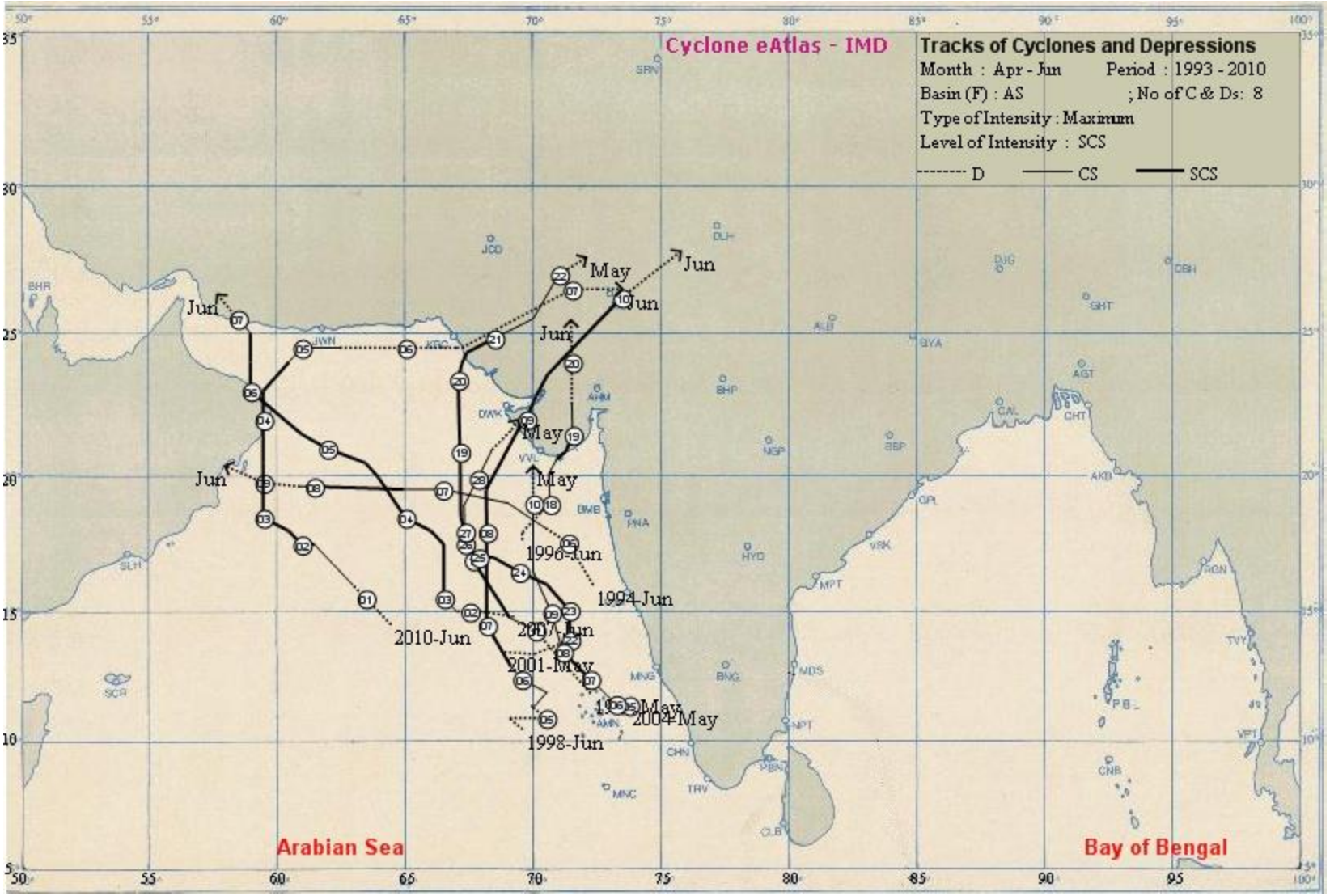
Nature, 2011





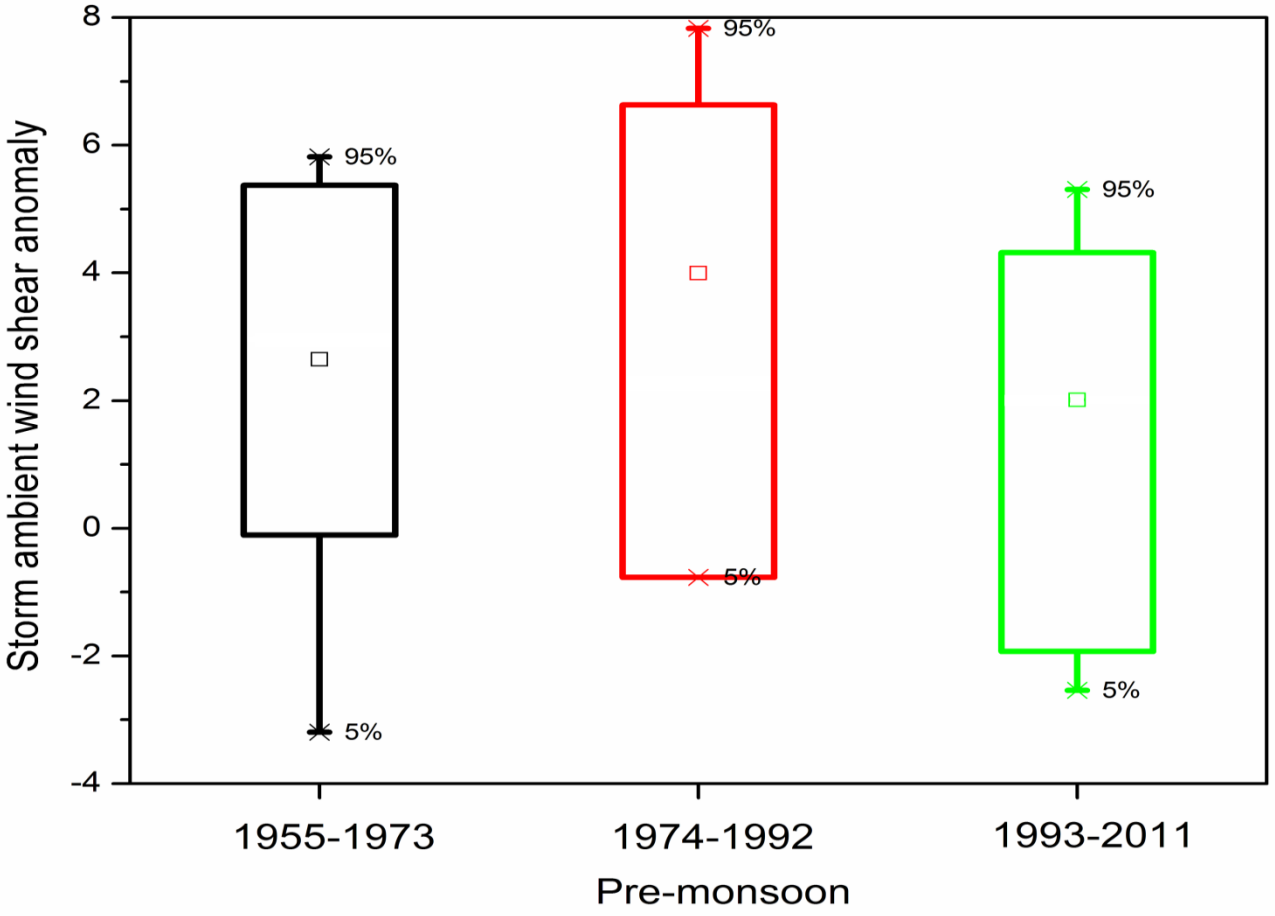

Cyclone eAtlas - IMD
Tracks of Cyclones and Depressions
Month : Apr - Jun Period : 1955 - 1973
Basin (F) : AS ; No of C & Ds: 6
Type of Intensity : Maximum
Level of Intensity : SCS
D
CS
SCS
Jun
Jun
1961-Jun
May
1964-Jun
May
May
1961-May
1960-May
1959-May
1963-May
Arabian Sea
Bay of Bengal


Cyclone eAtlas - IMD
Tracks of Cyclones and Depressions
Month : Apr - Jun Period : 1974 - 1992
Basin (F) : AS ; No of C & Ds: 4
Type of Intensity : Maximum
Level of Intensity : SCS
D
CS
SCS
Jun
Jun
May
Jun
1977-Jun
1979-Jun
1976-May
1975-May
Arabian Sea
Bay of Bengal


Cyclone eAtlas - IMD
Tracks of Cyclones and Depressions
Month : Apr - Jun Period : 1993 - 2010
Basin (F) : AS ; No of C & Ds: 8
Type of Intensity : Maximum
Level of Intensity : SCS
D
CS
SCS
Arabian Sea
Bay of Bengal
Jun
May
Jun
Jun
May
Jun
May
Jun
May
1996-Jun
1994-Jun
2007-Jun
2010-Jun
2001-May
2004-May
1998-Jun

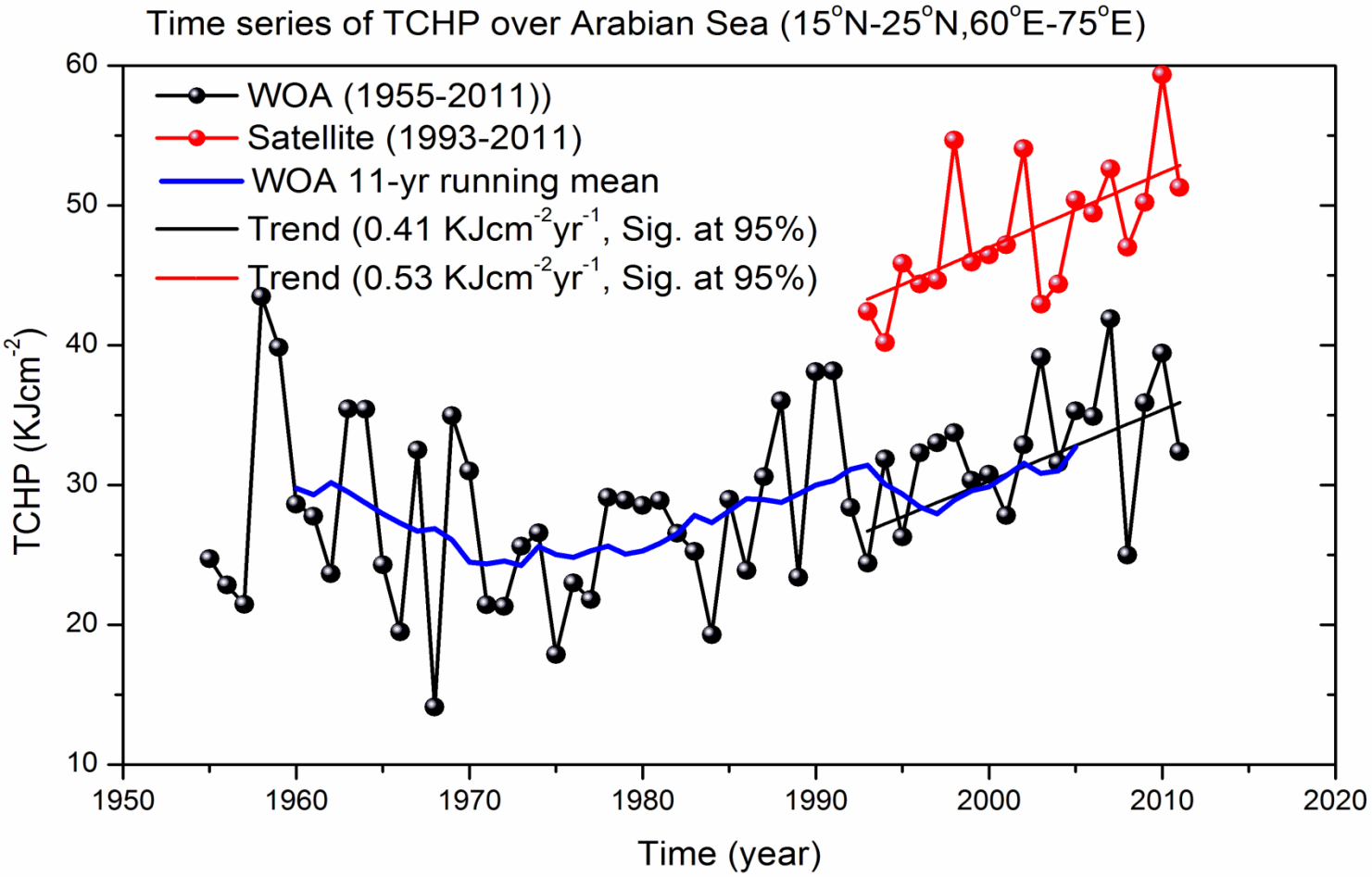
	1955-1973	1974-1992	1993-2011
Frequency of intense TCs (severe cyclonic storm and above)	6	4	7
Days of intense TCs	17	6	20

Variation of vertical wind shear



Rajeevan et al. 2013, Atmospheric Science Letters

Variation of Tropical Cyclone Heat Potential



Rajeevan et al. 2013, Atmospheric Science Letters

Conclusions

- It is important to understand the role of atmospheric constituents including aerosols on monsoon circulation and rainfall, both using observations and models.
- However, it is very important to consider the natural variability of monsoon before any conclusions are drawn about the impact of atmospheric constituents on monsoon.