Dynamics and processes of Asian-Australian Monsoon

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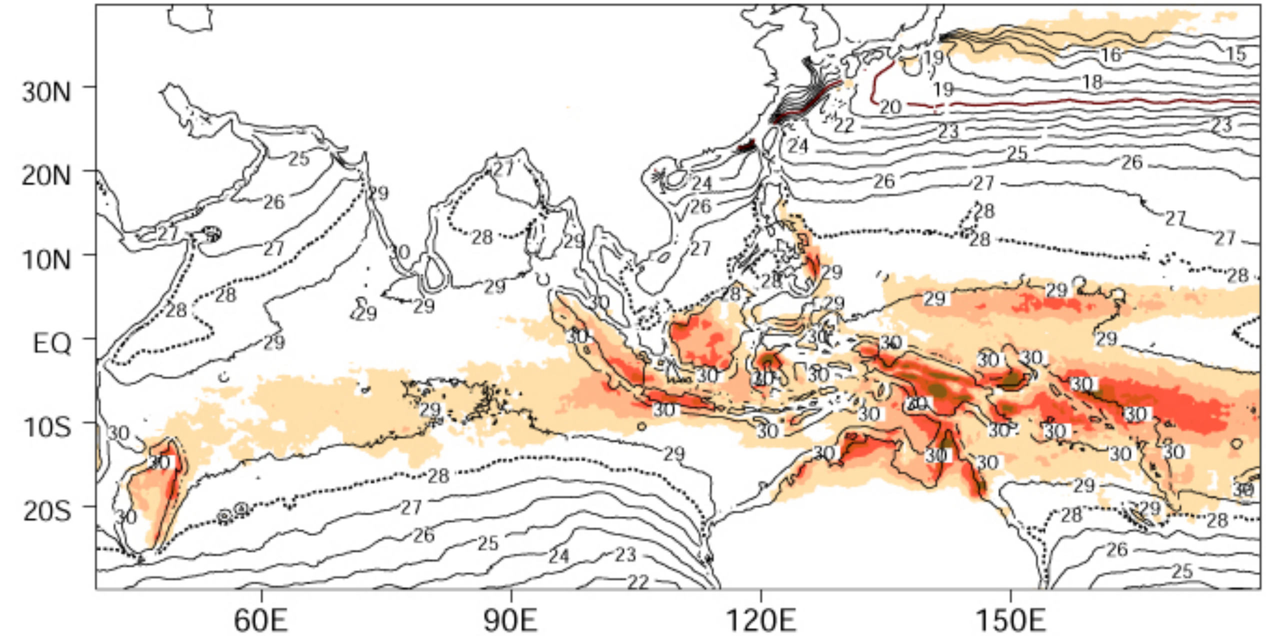
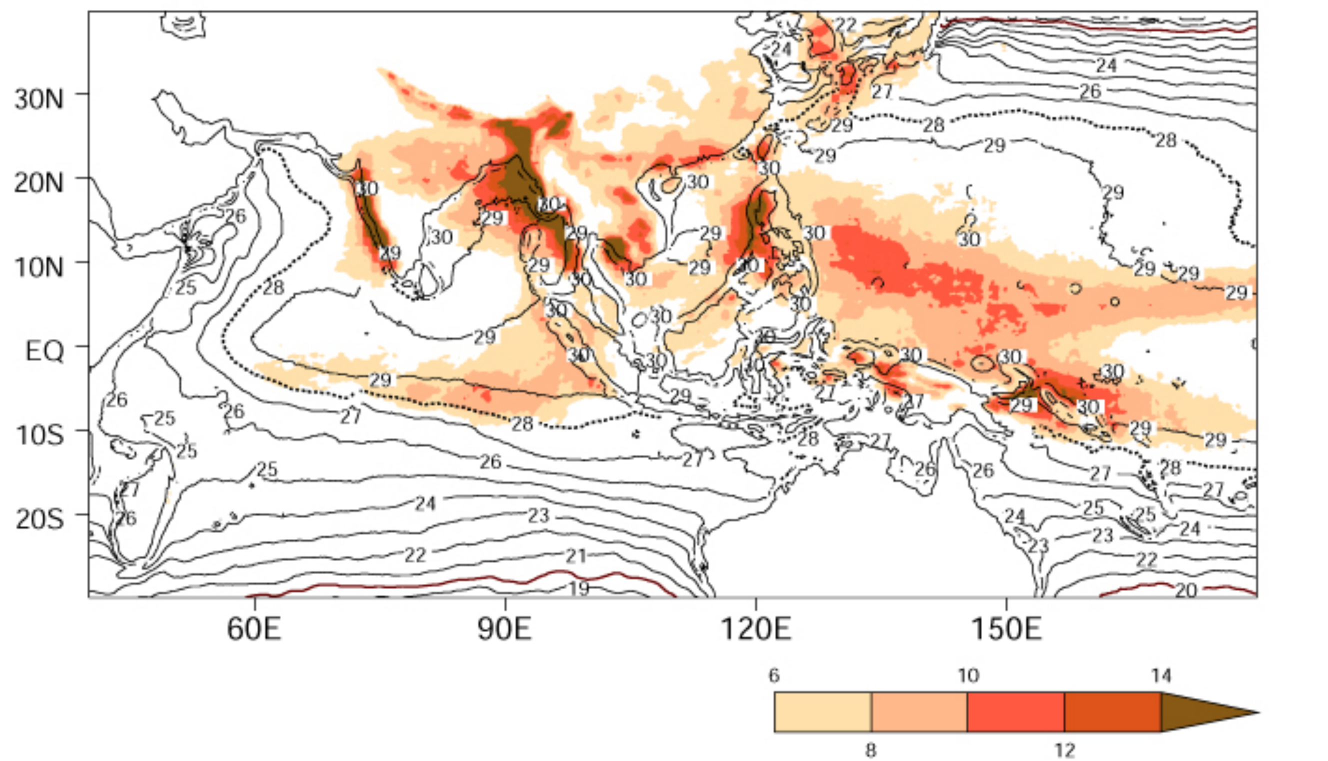
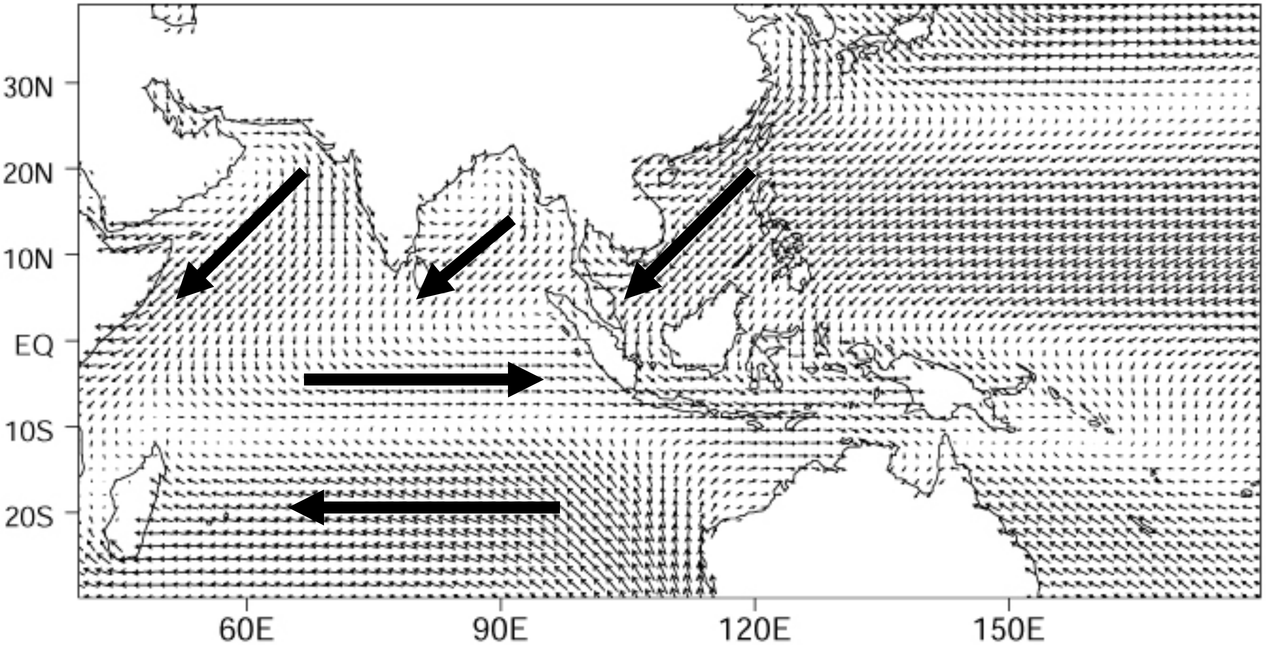


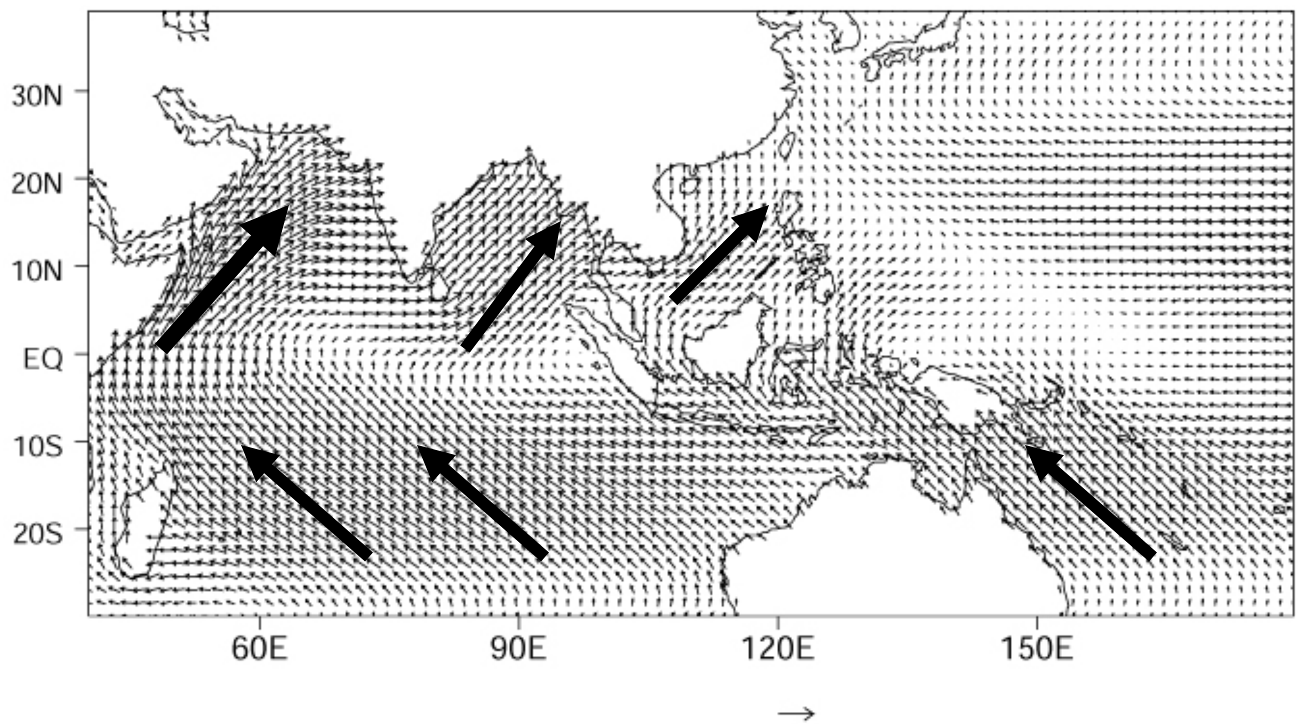
TRMM SST, Pr (DJF)

TRMM SST, Pr (JJA)

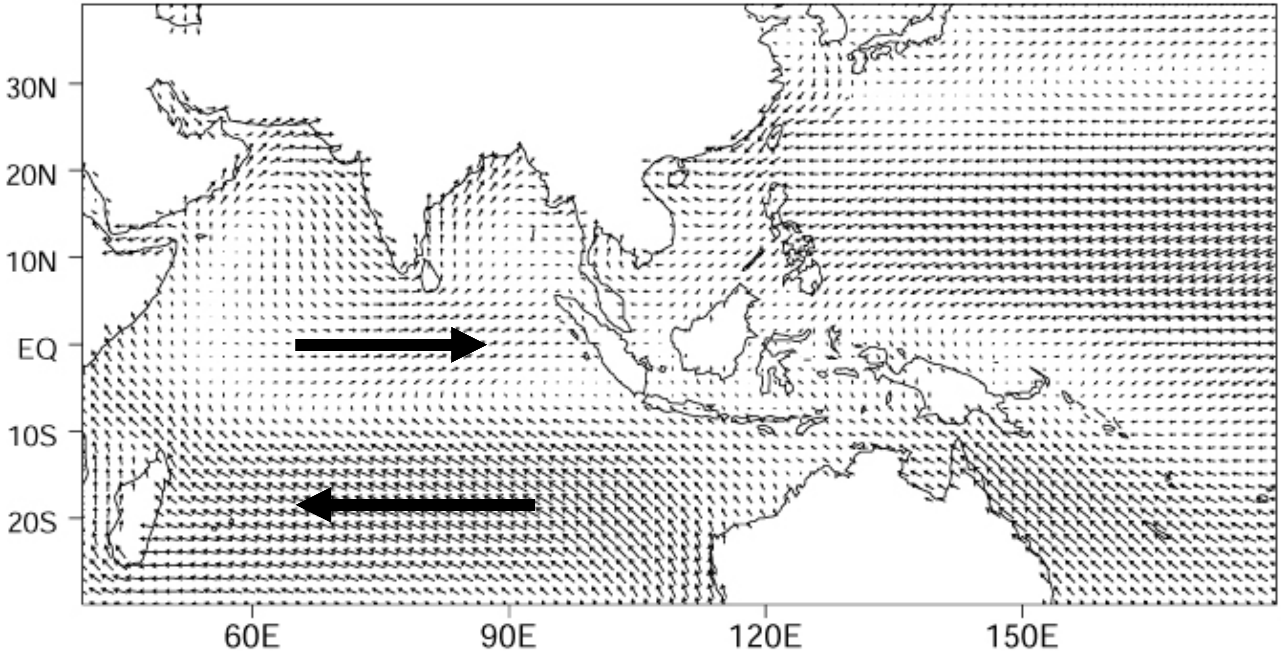




QSCAT winds (DJF)

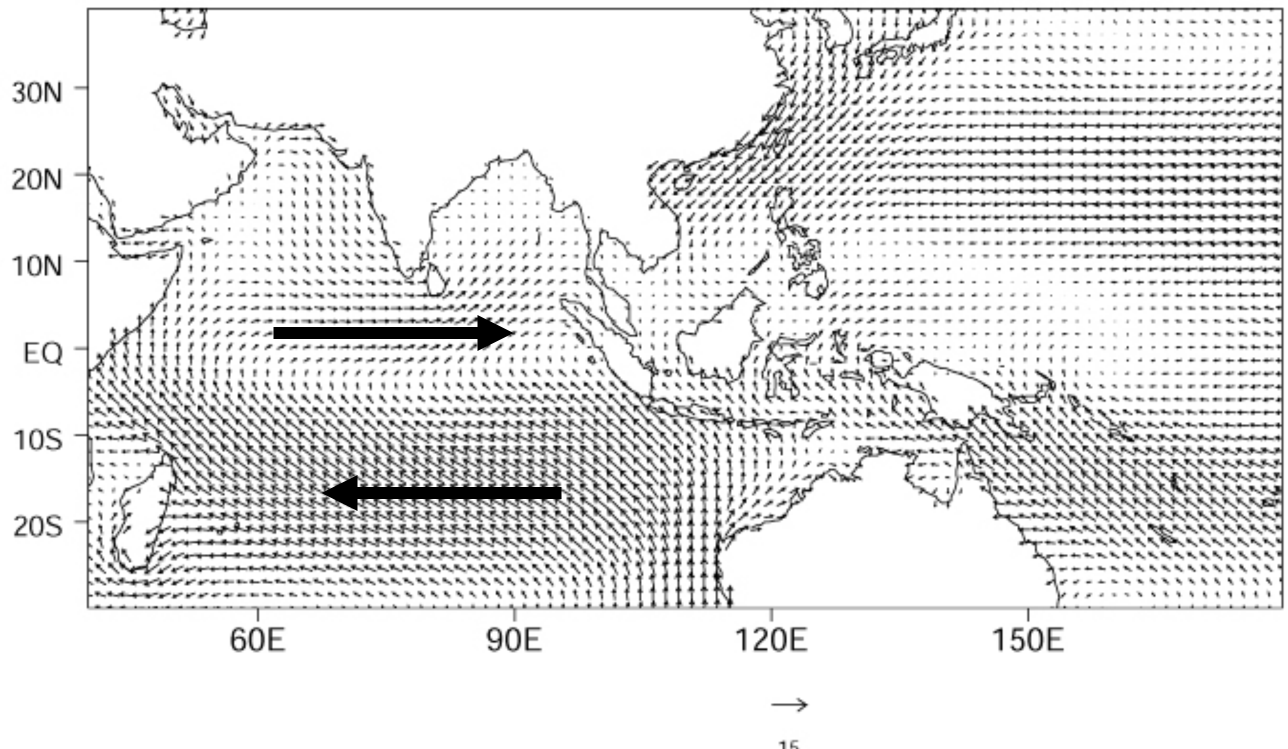


QSCAT winds (JJA)



QSCAT winds (MAM)

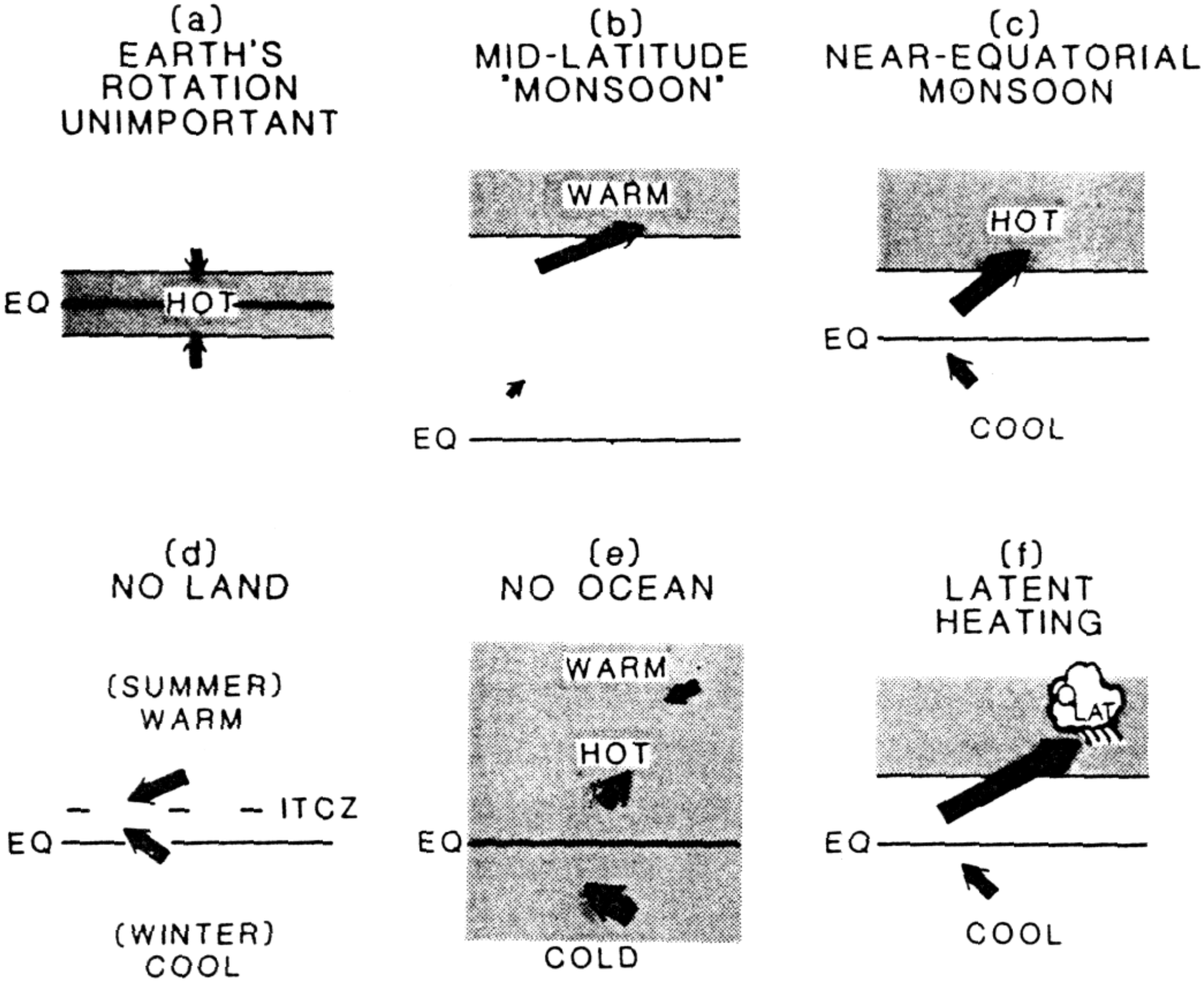
QSCAT winds (SON)



Why are there monsoons?

Monsoon Annual Cycle – Robust ?

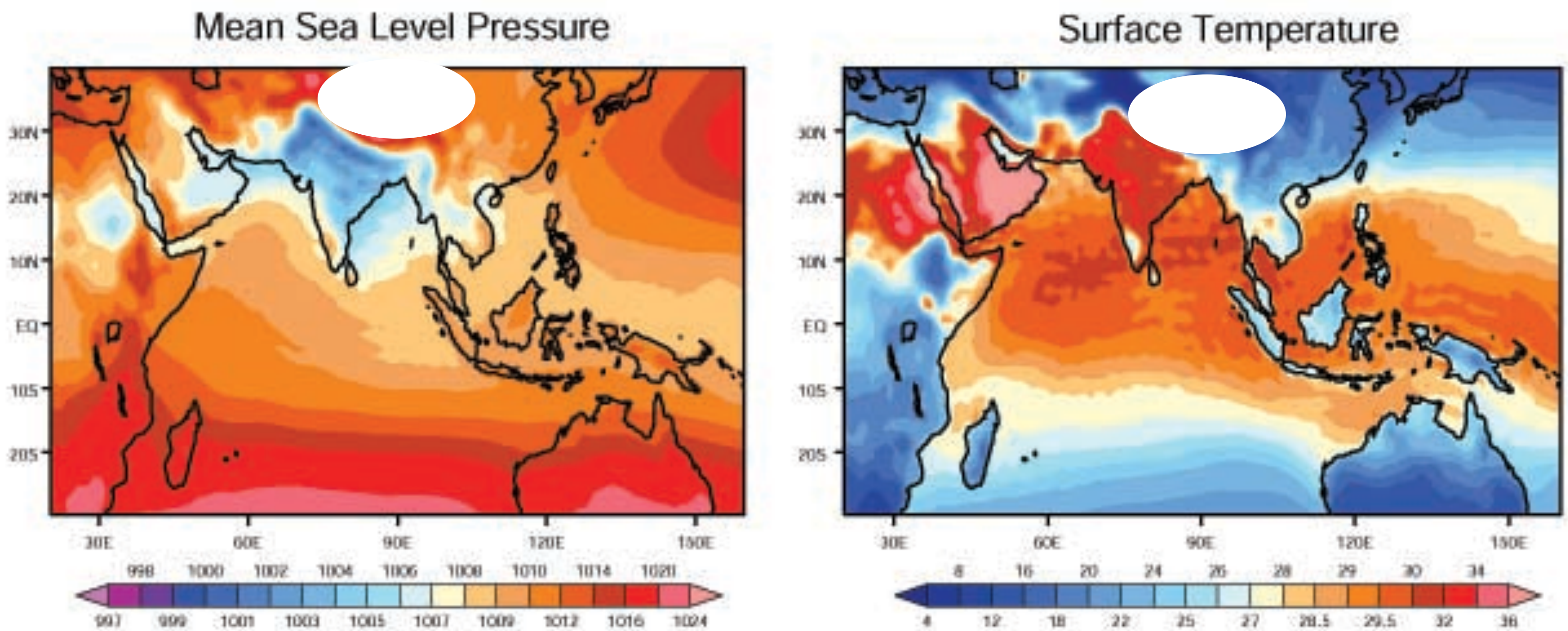
- land-sea thermal contrast (Ts/Ps gradient)
- Orography (Tibet – elevated heat source)
  (East Africa – frictional force
  cross-equatorial flow)
- Earth's rotation (Coriolis force)
- Moisture from the tropical Indian Ocean



"land – shaded"

Young, 1987 – a chapter in Fein and Stephens (1987)
Hoskins and Wang (2004) – a chapter in Bin Wang (2004) –
Vorticity and thermodynamics perspective

Patterns for May



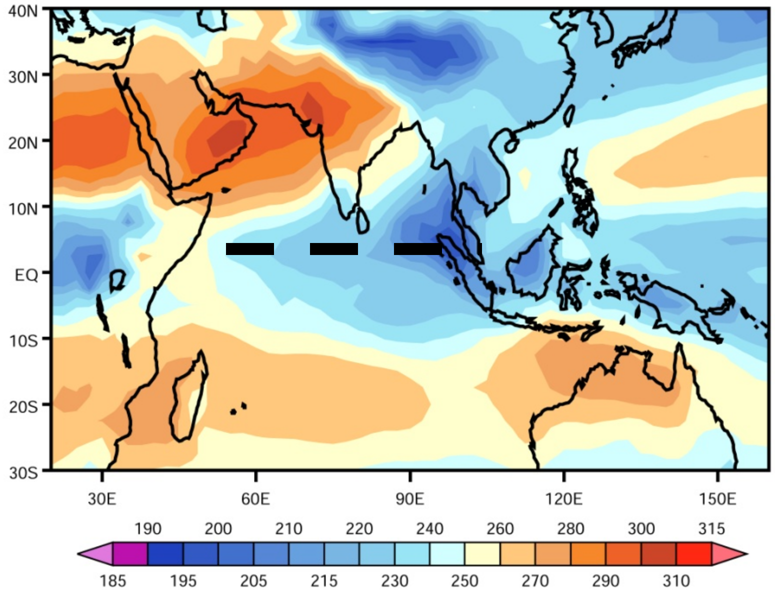
(i) Slowly, due to surface heating and attendant sensible heat flux, shallow low-pressure forms over land

(ii) This low, gradually generates low-level wind inflow that draws moisture from the ocean to the south

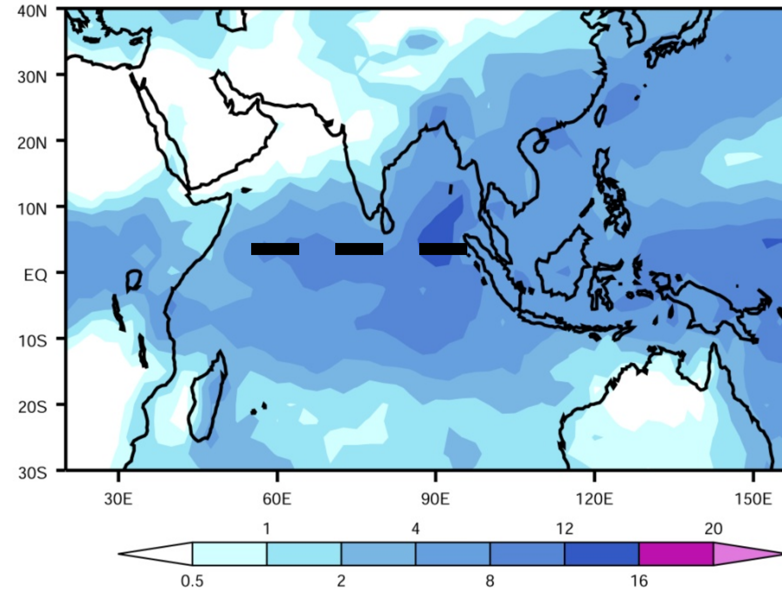
(iii) The moisture is carried upward by the convection, condenses, and warms the upper troposphere, where an anticyclone forms

Patterns for May

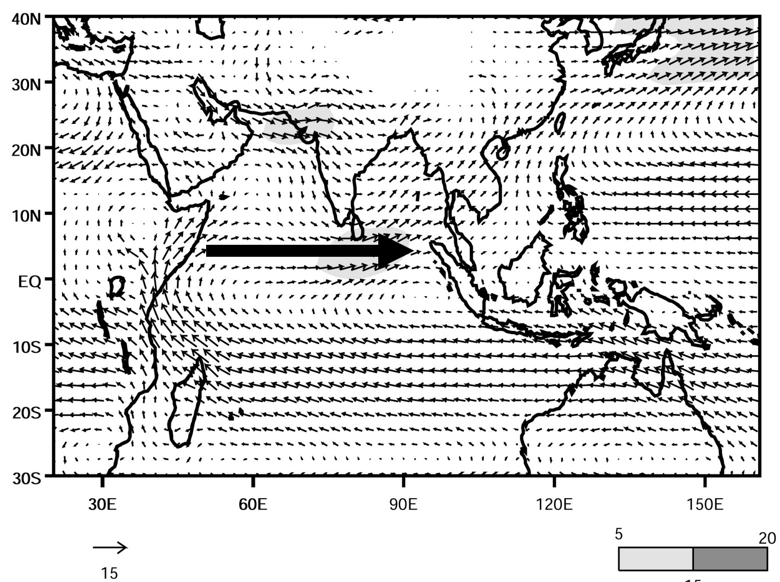
OLR



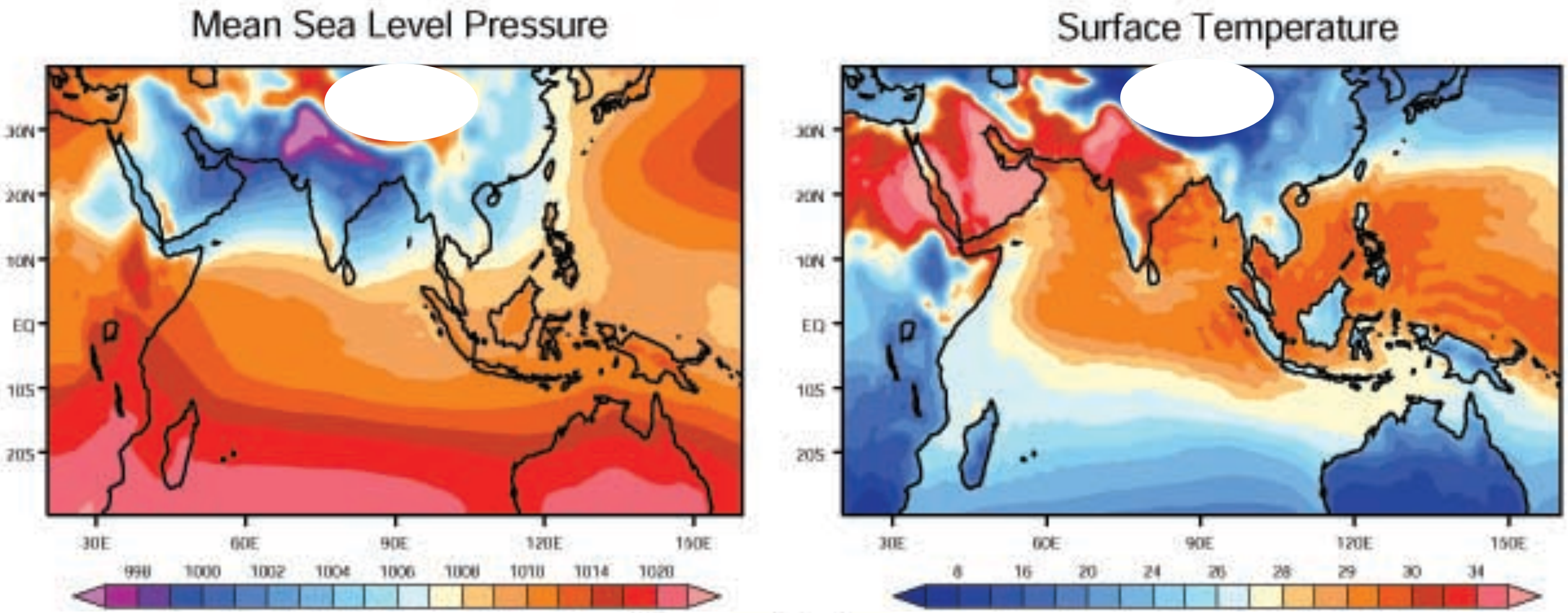
Precipitation (Xie-Arkin)



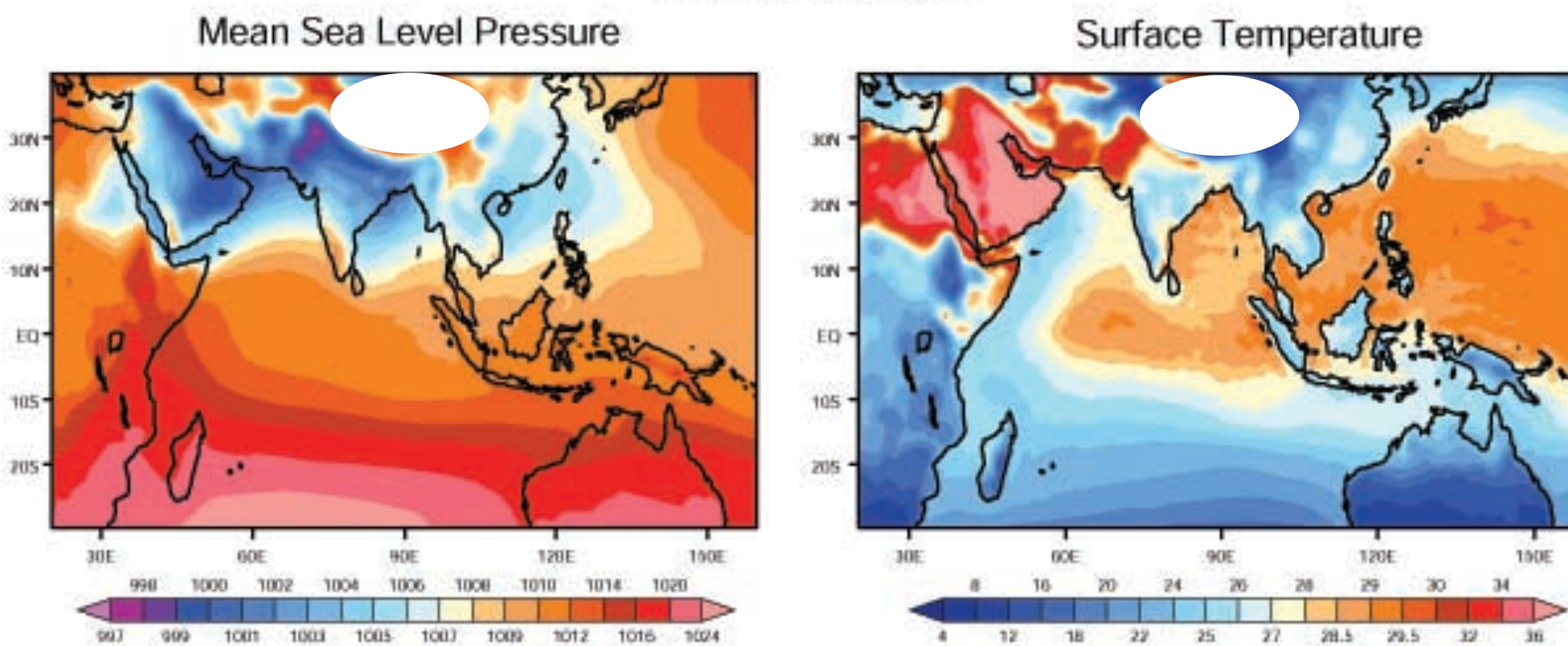
850hPa



Patterns for June



Patterns for August



Mean Upper-Tropospheric Temperature: 200-500 mbar

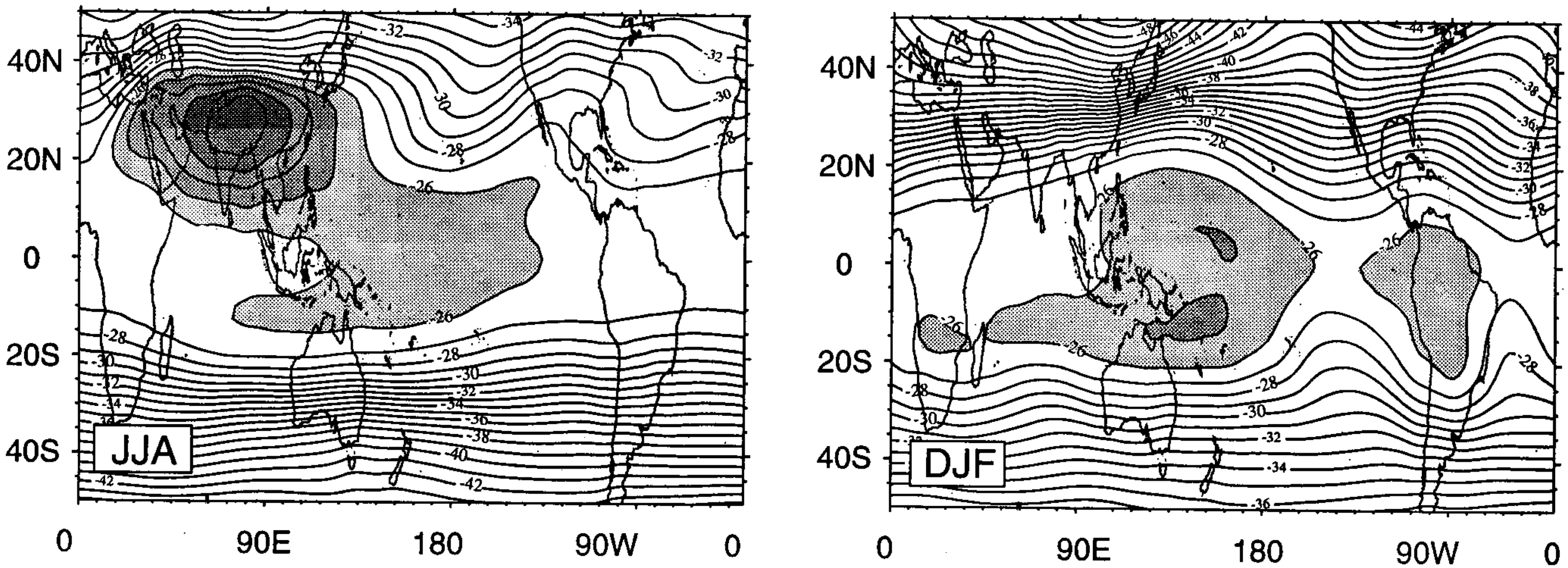


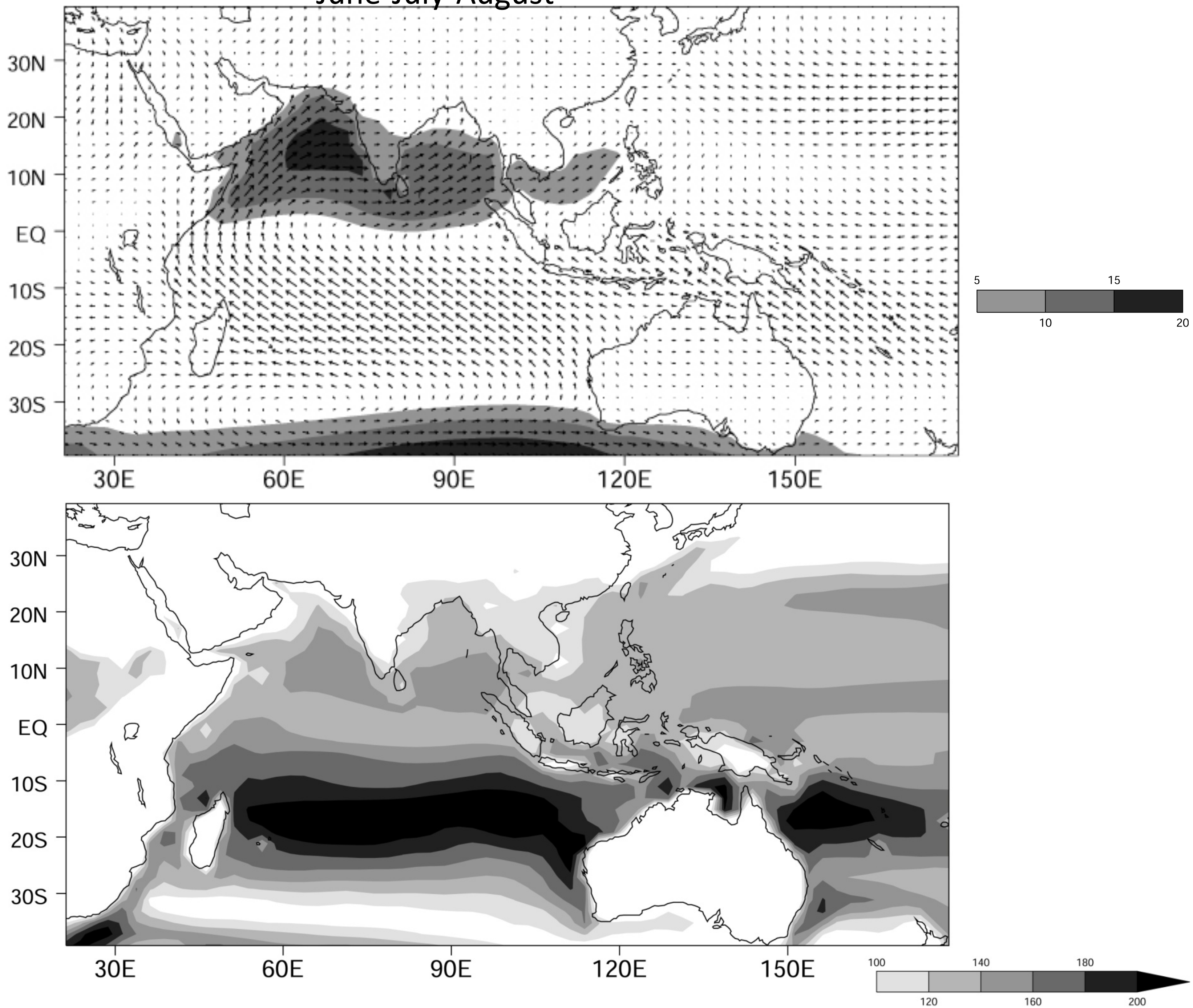
Figure 6a. Mean upper tropospheric (200–500 mbar) temperature (degrees Celsius) for the boreal summer (JJA), and boreal winter (DJF), averaged between 1979 and 1992. The boreal summer plot is based on calculations first made by *Li and Yanai* [1996]. Mean columnar temperatures warmer than –25°C are shaded.

Webster et al. (1998, J. Geophys. Res)

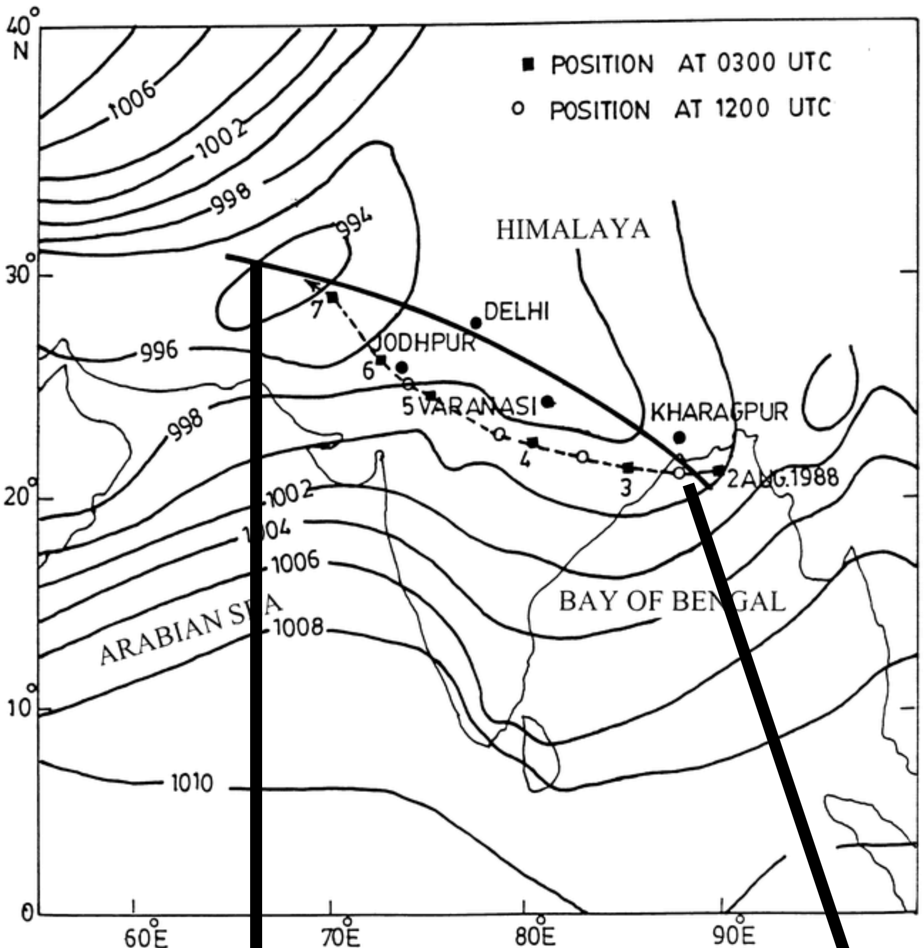
June-July-August

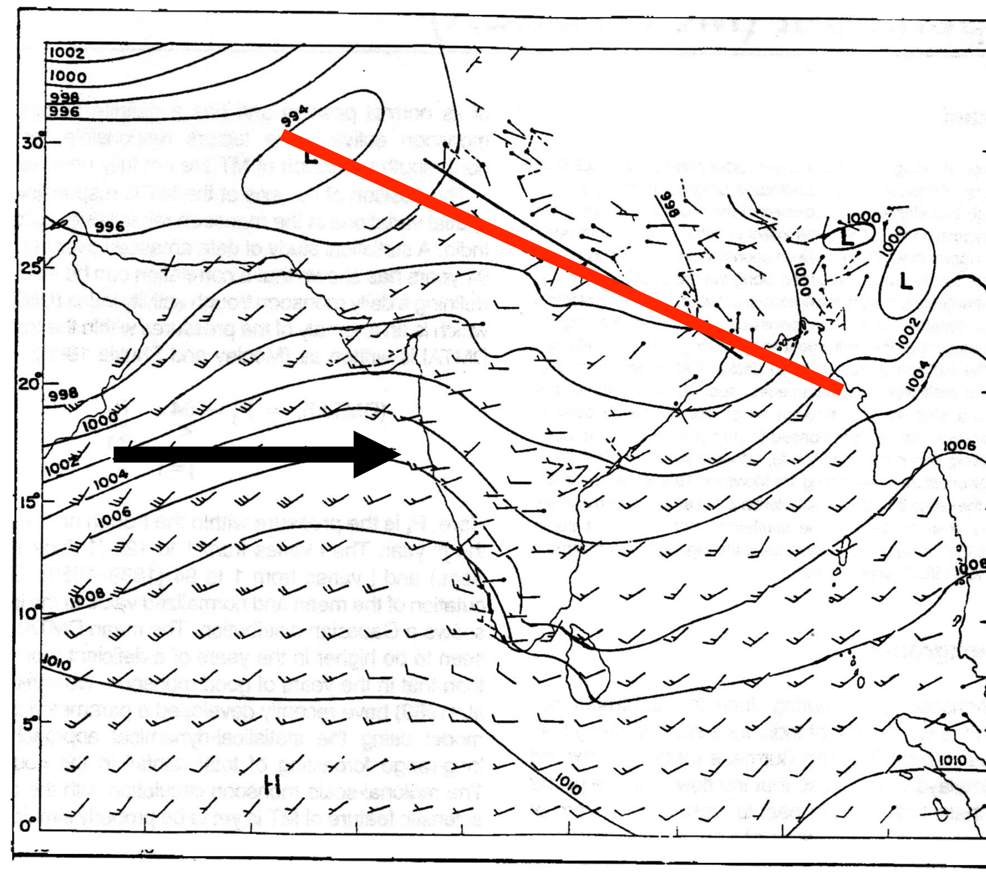
10 m wind

Evaporation (mm)



Normal position of the monsoon trough





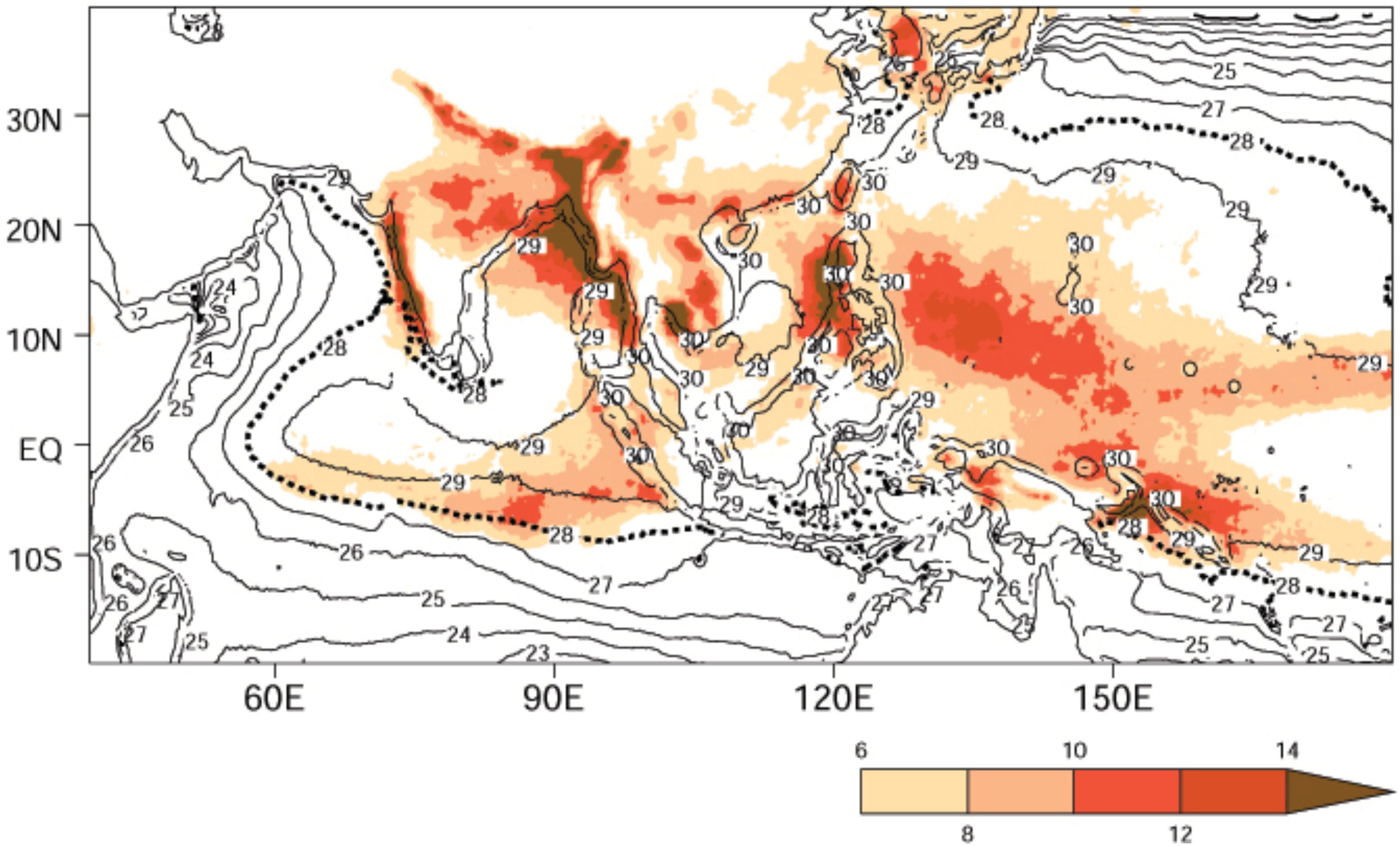
"west-east moisture gradient"

Heat low – dry weather
Pakistan

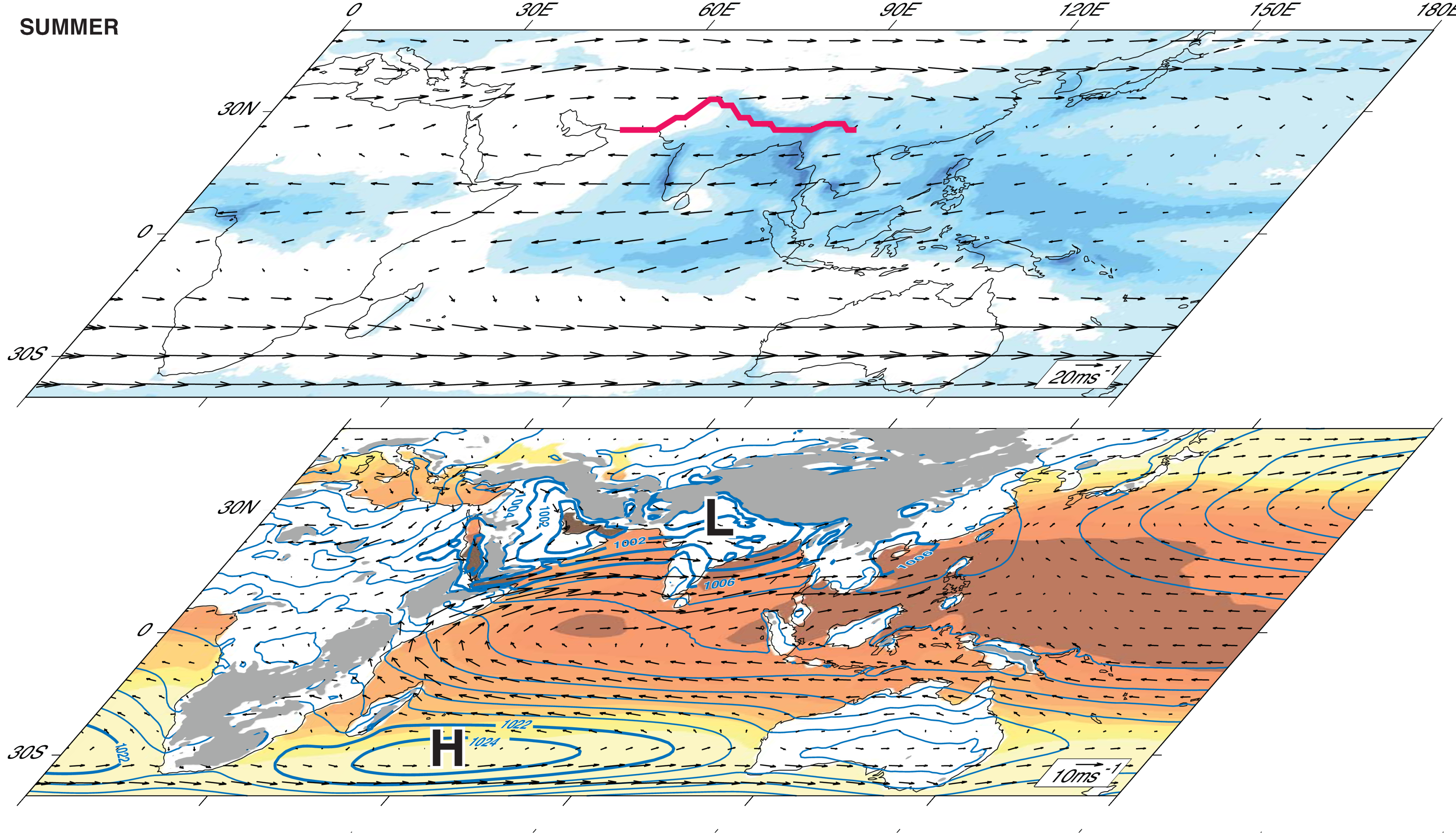
Moist low

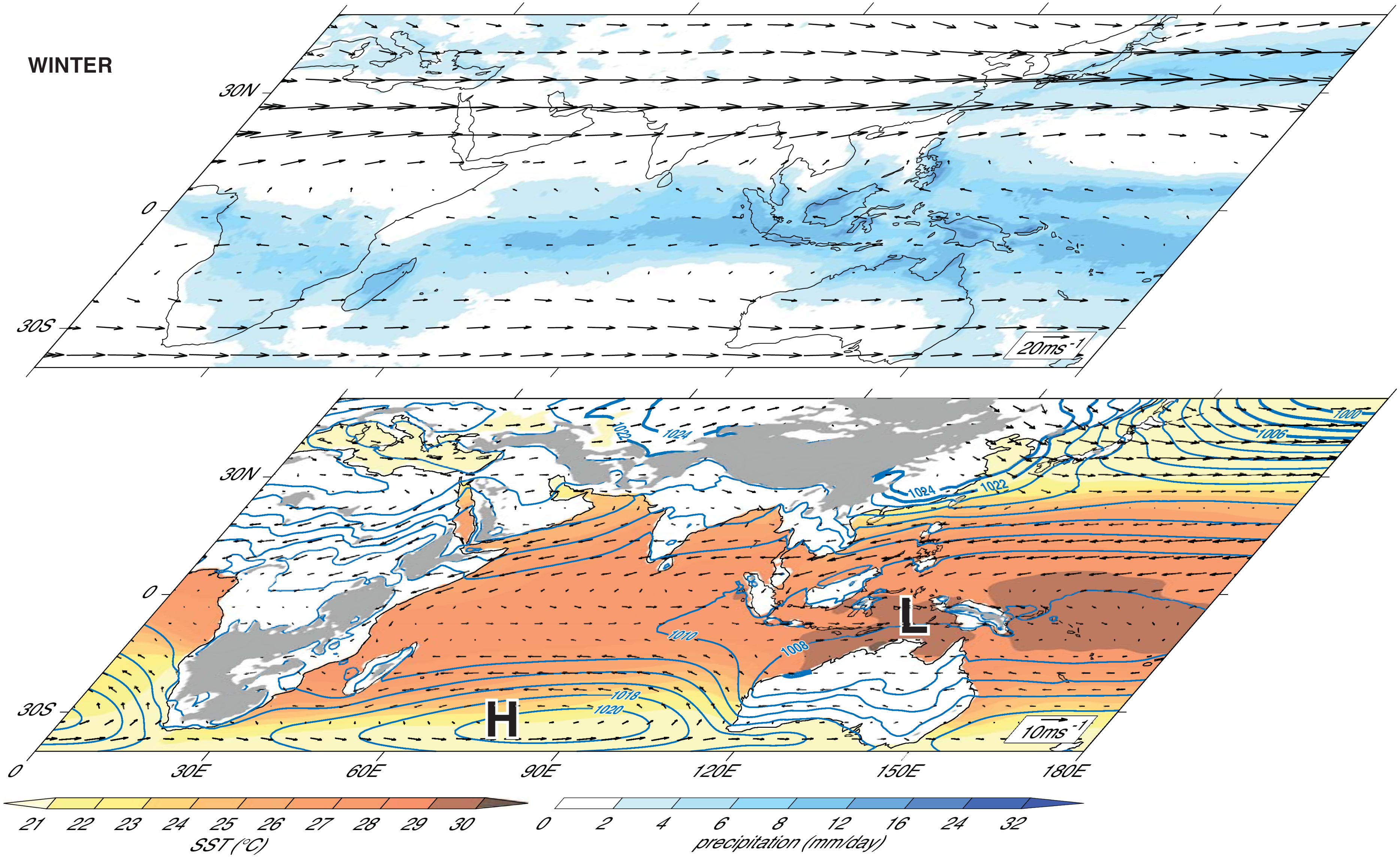
"analogous to the equatorial trough"
"seasonal displacement of the TCZ"
"shear vorticity – Ekman pumping"

JJAS – Precipitation and SST Climatology



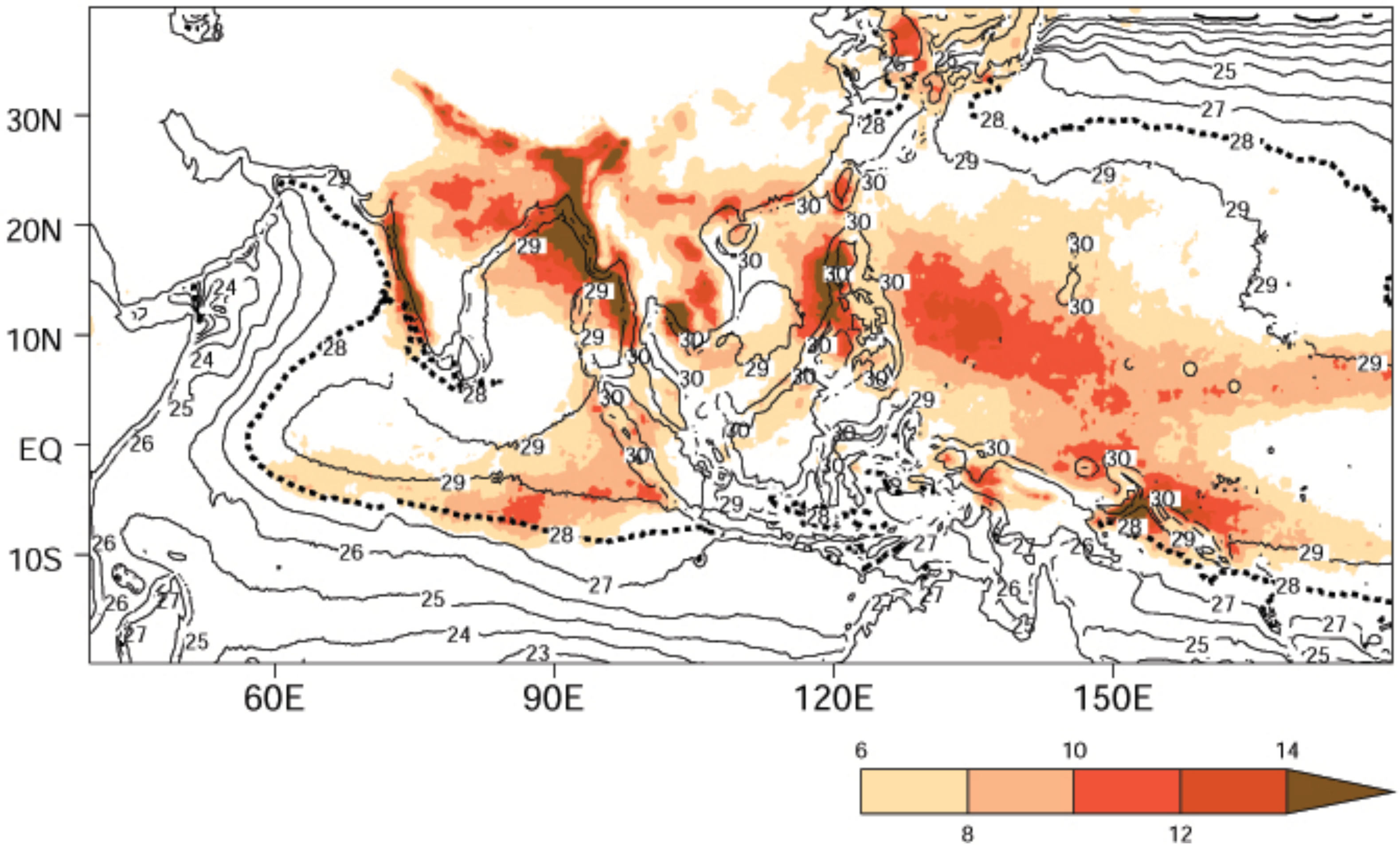
“Three regional heat sources”


SUMMER
0
30E
60E
90E
120E
150E
180E
30N
0
30S
20ms -1
1004
1002
1002
1006
1006
L
H
1022
1024
1022
10ms -1



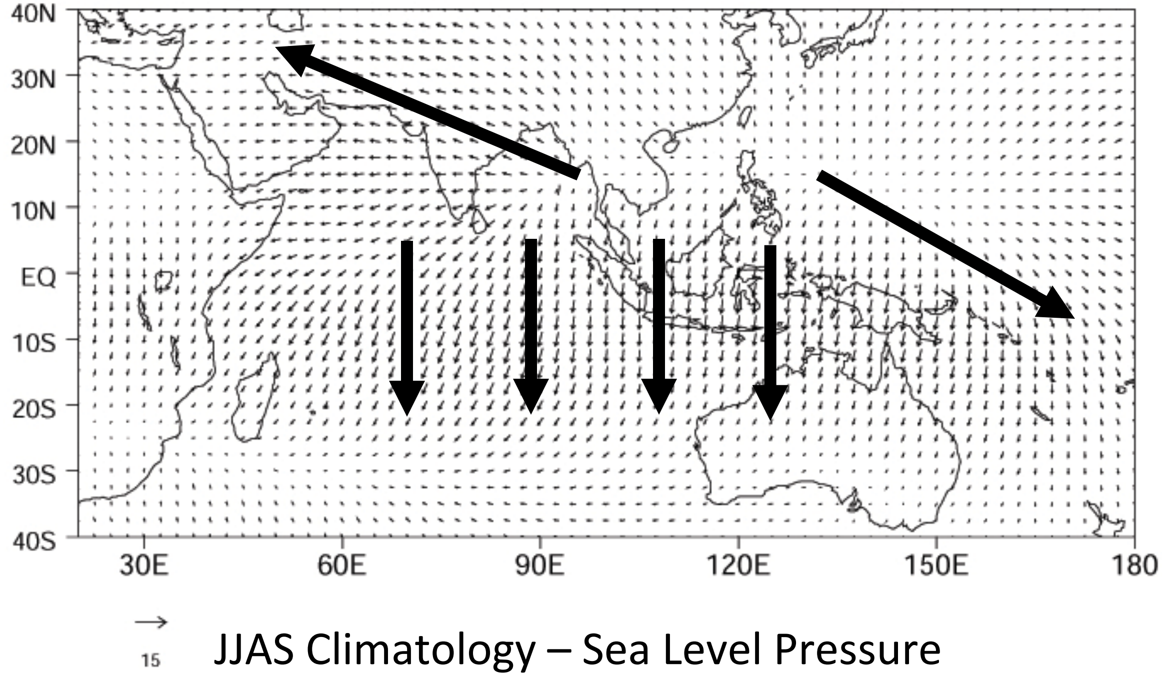
WINTER
30N
0
30S
20ms -1
1022
1024
1024
1022
1000
1006
1010
1008
1018
1020
H
L
10ms -1
0
30E
60E
90E
120E
150E
180E
21
22
23
24
25
26
27
28
29
30
SST (°C)
0
2
4
6
8
12
16
24
32
precipitation (mm/day)

JJAS – Precipitation and SST Climatology

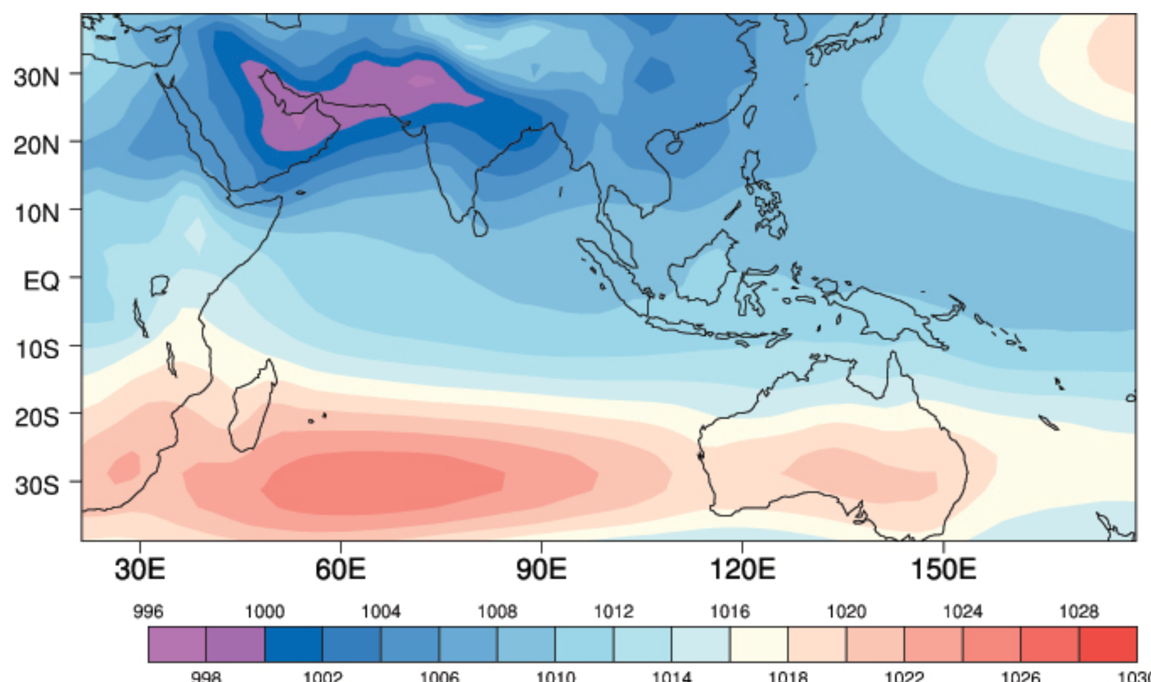


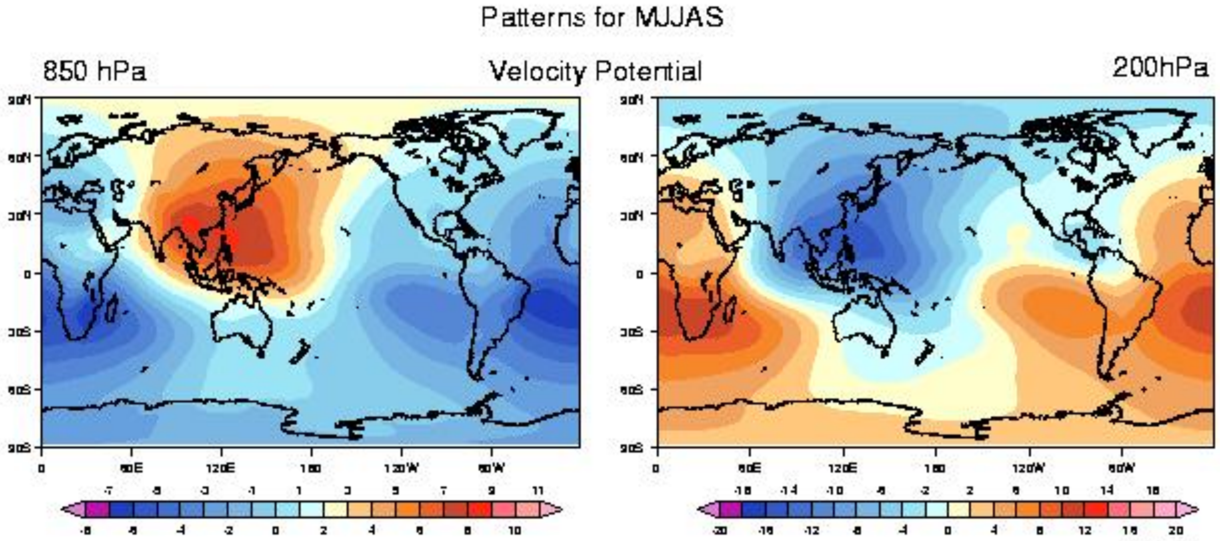
“Three regional heat sources”

JJAS Climatology – divergent wind at 200hPa



JJAS Climatology – Sea Level Pressure

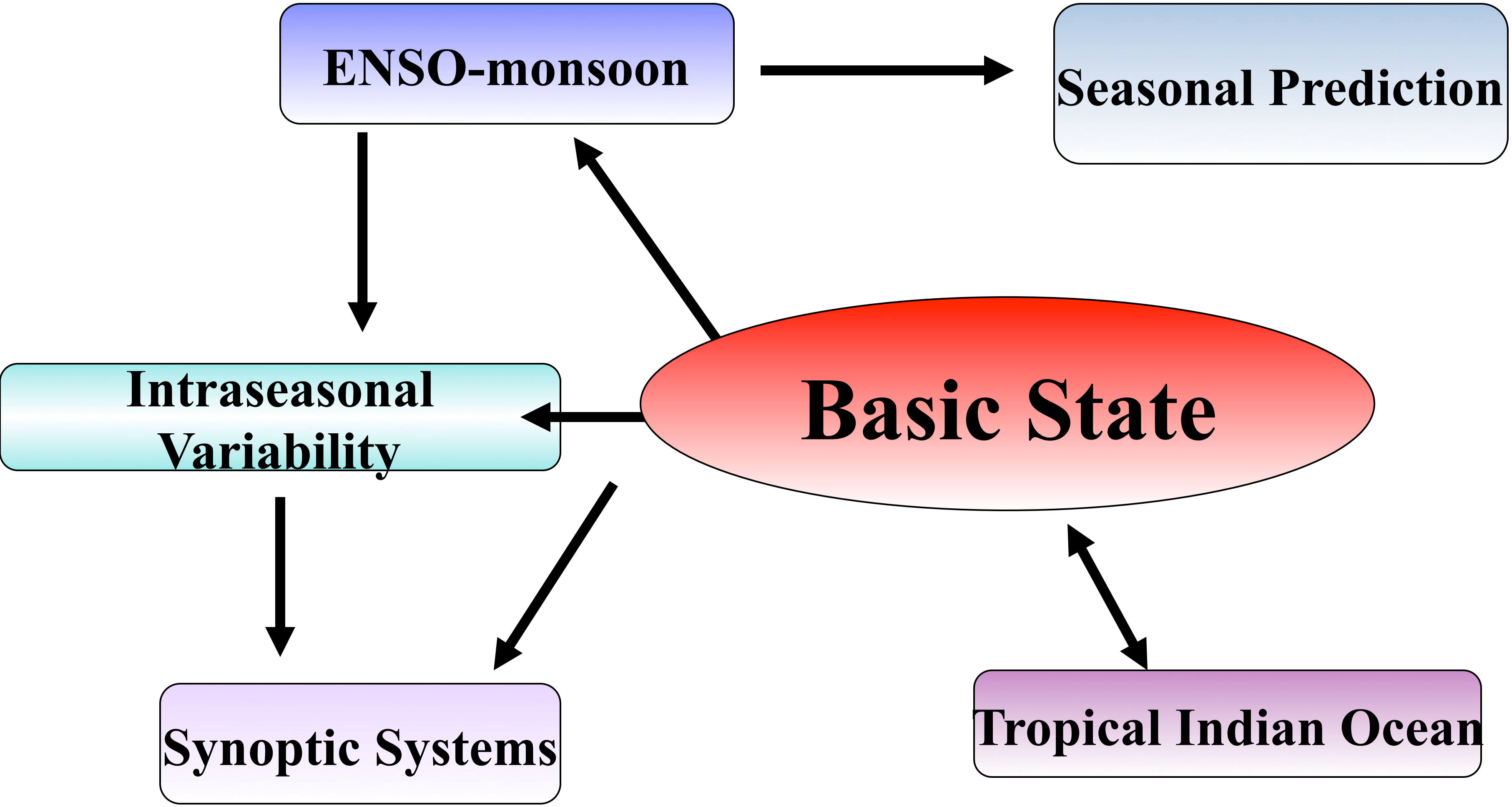




(i) Lateral monsoon (Hadley) Circulation

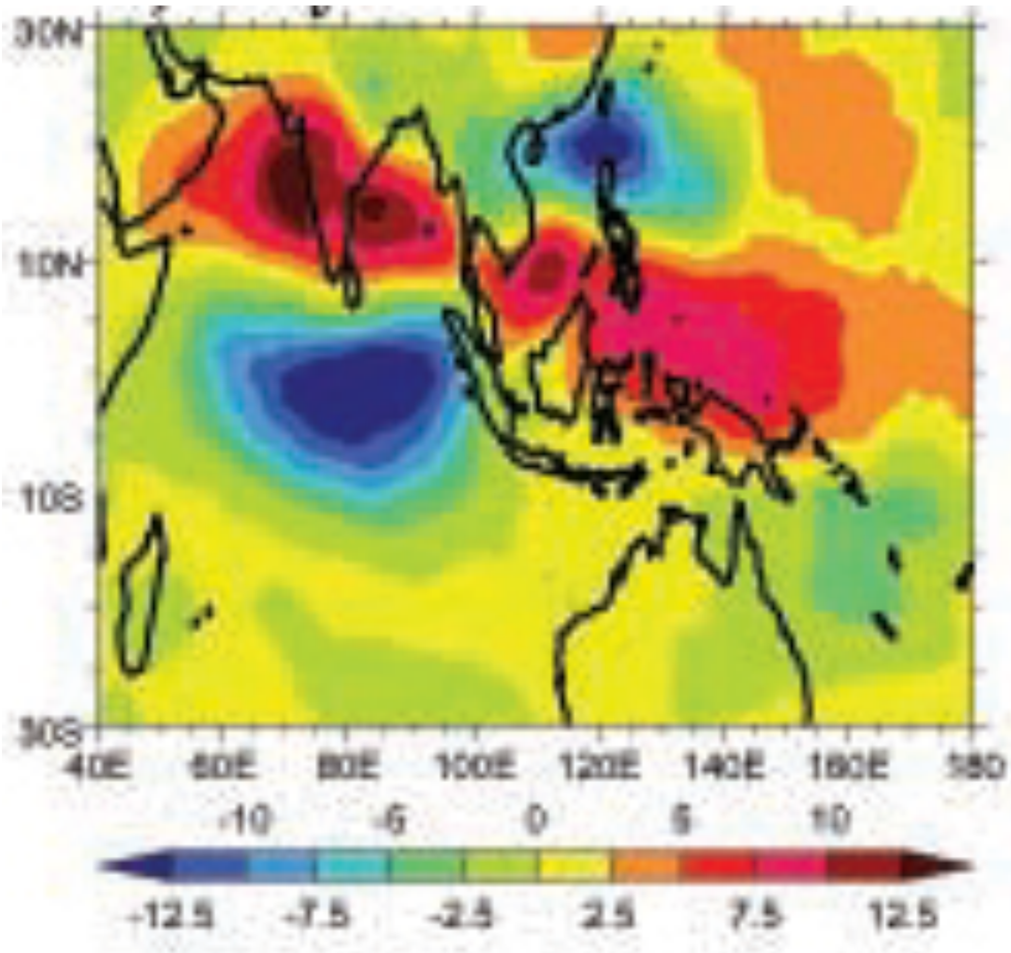
(ii) Planetary Walker Circulation – ENSO

(iii) Transverse monsoon circulation



"Importance of understanding and simulating the mean monsoon – basic state"

Observed Boreal Summer ISV



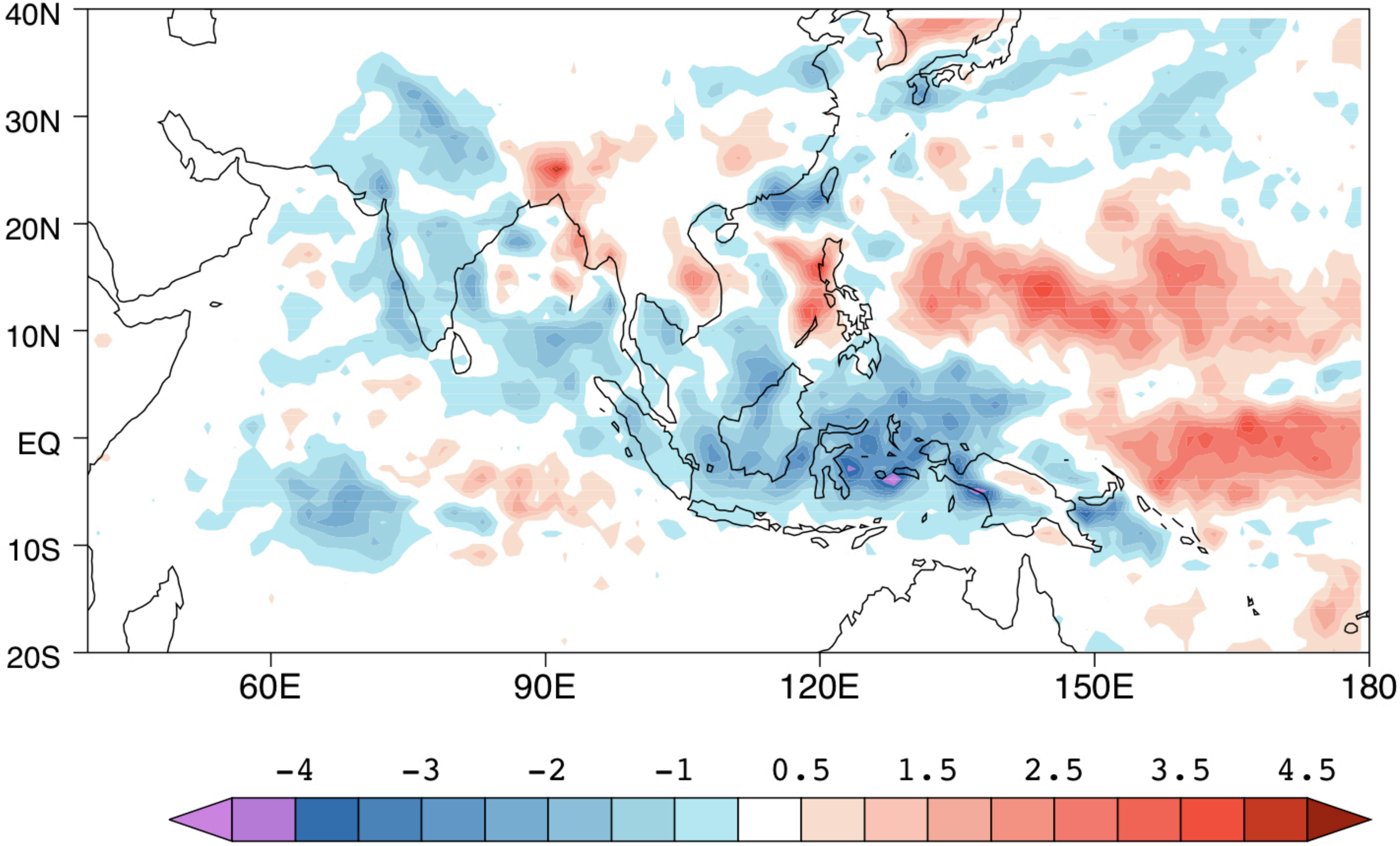
OLR anomalies W/m^2

"internal dynamics"

Annamalai and Sperber (2005, JAS)
Lau and Chan (1986, JAS)

"one-phase of the ISV"

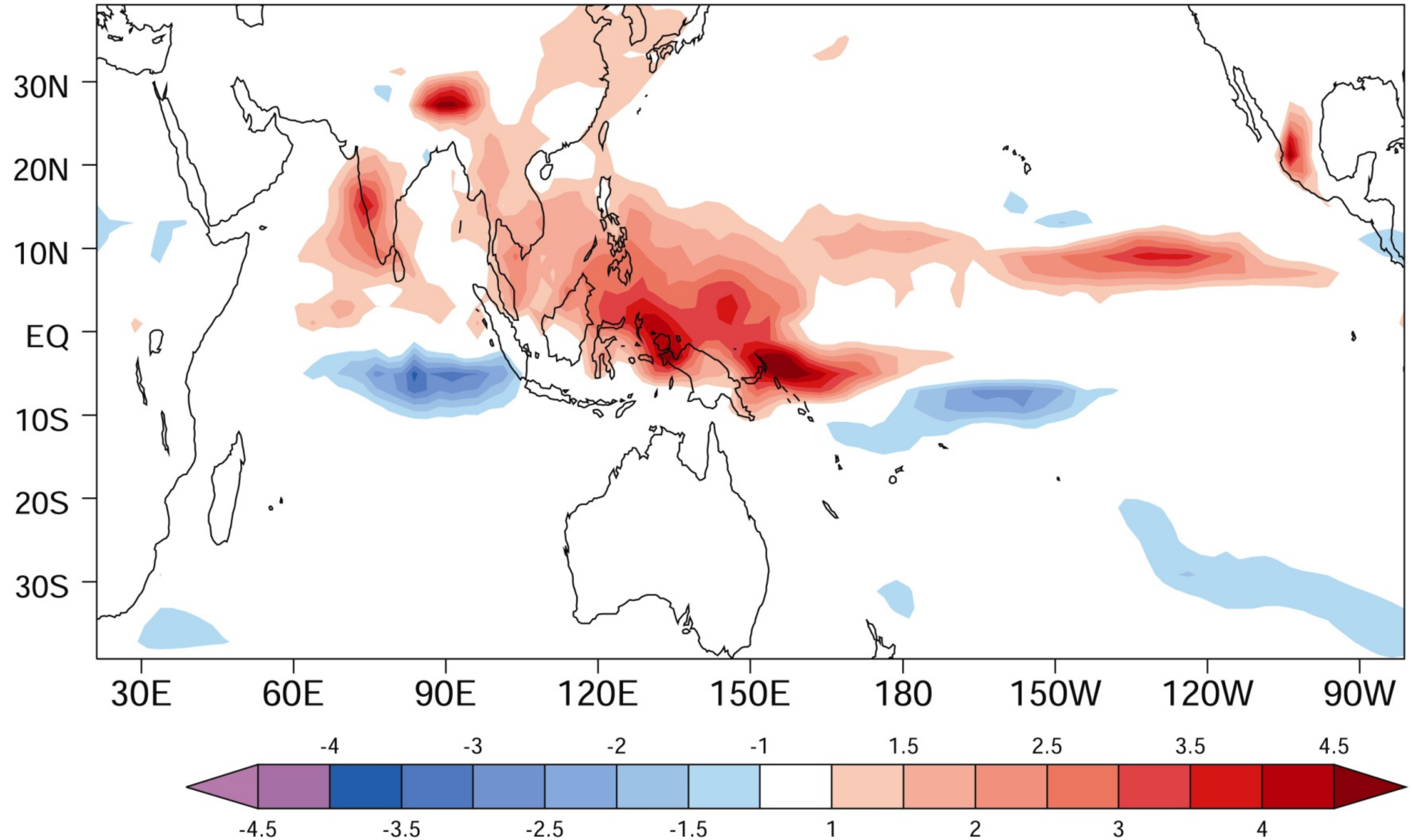
JJAS rainfall anomalies (2002/04/09) - TRMM



"Boundary forcing"

JJAS Precipitation response in CM_2.1

$4xCO_2$ *minus* 20c3m



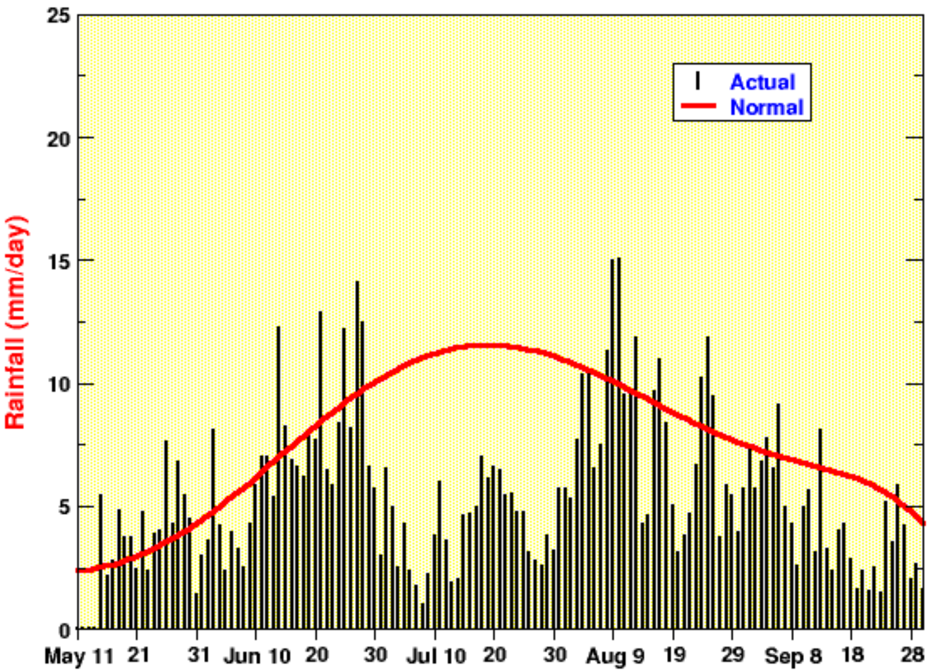
(*mm/day*)

Stowasser, Annamalai and Hafner (2009 J. Climate)

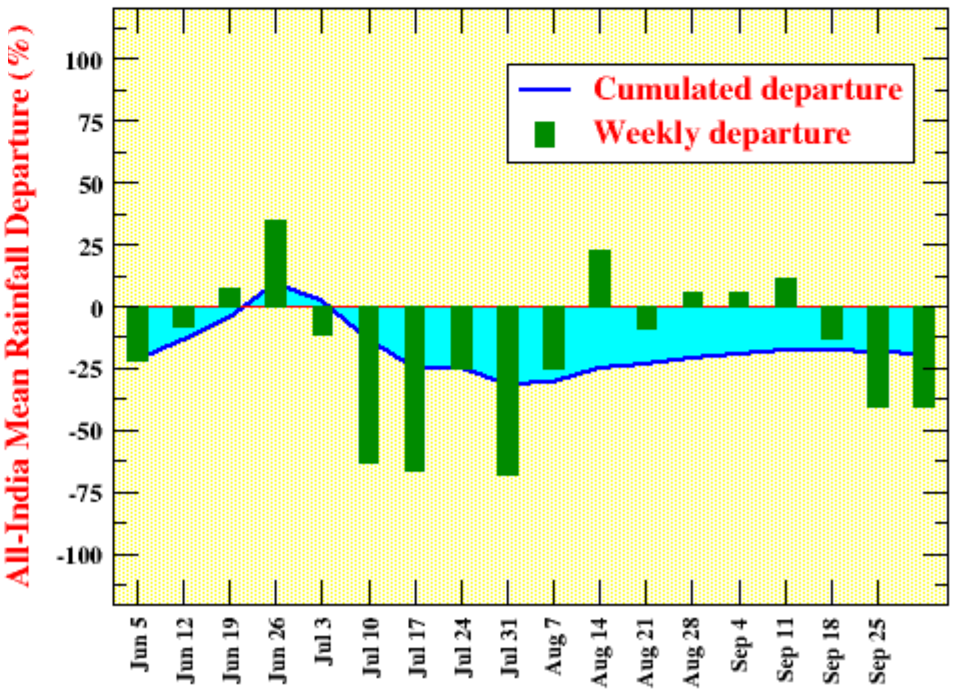
Overarching Hypothesis

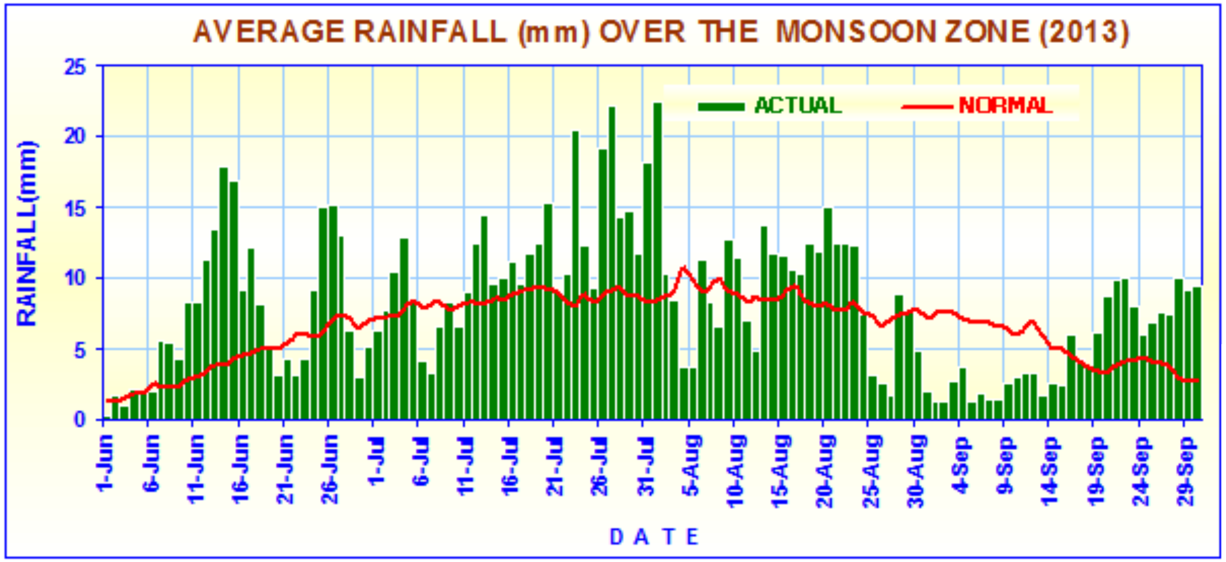
Interaction between equatorial waves and moist physics needs to be understood for attributing the causes for precipitation anomalies over "mean ascent" regions

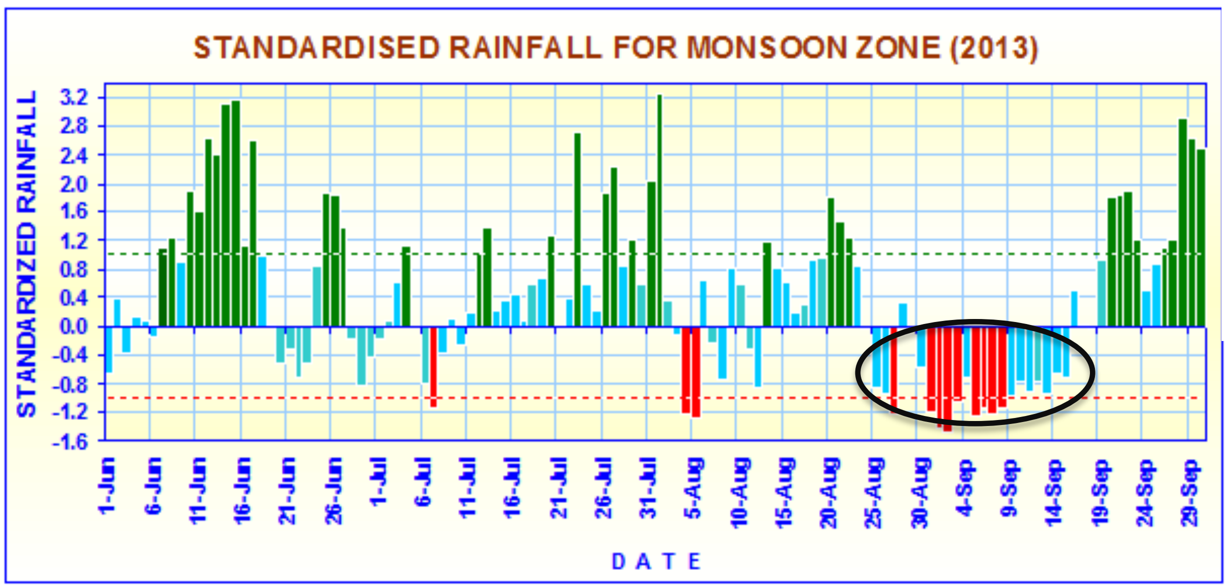
Daily Observed rainfall over India - 2002

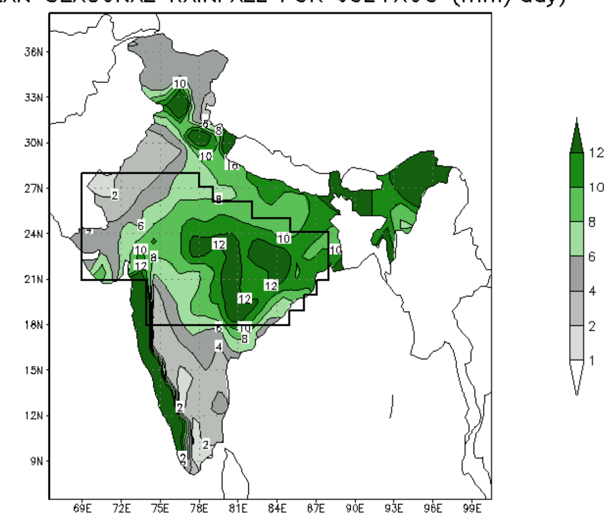


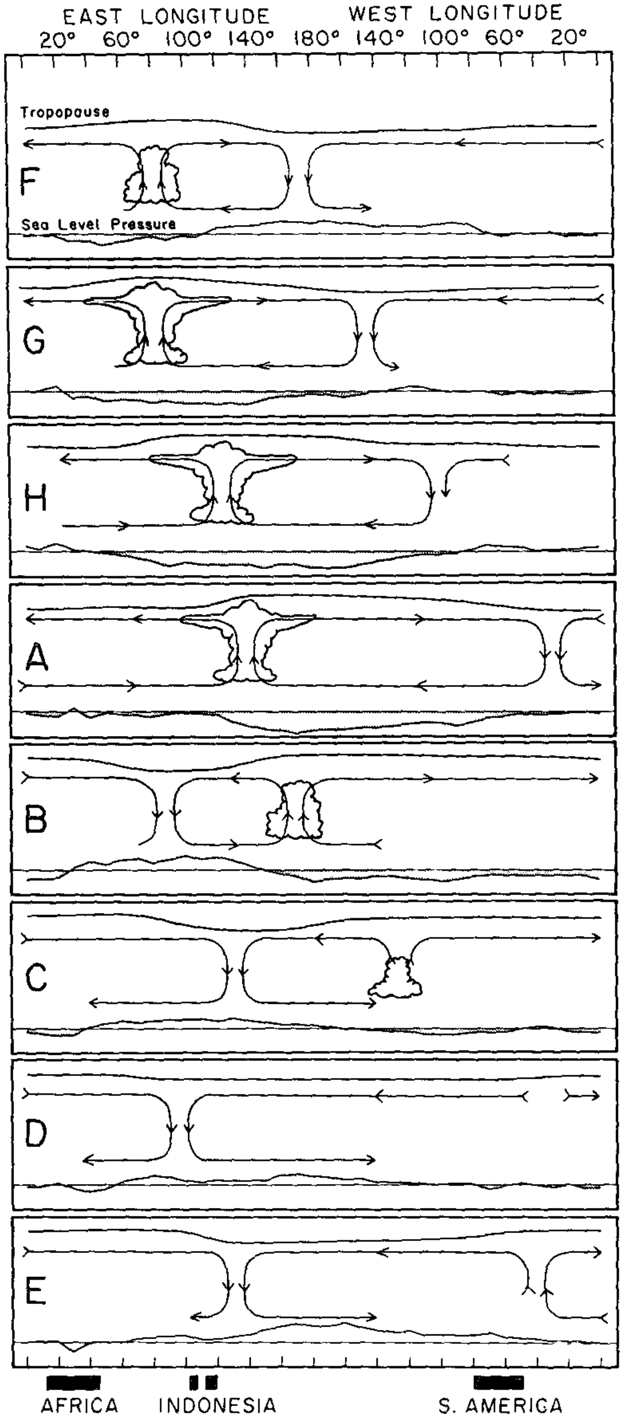
Weekly rainfall departure




AVERAGE RAINFALL (mm) OVER THE MONSOON ZONE (2013)
ACTUAL
NORMAL
RAINFALL(mm)
DATE


STANDARDISED RAINFALL FOR MONSOON ZONE (2013)
STANDARDIZED RAINFALL
DATE


MEAN SEASONAL RAINFALL FOR JUL+AUG (mm/day)



Madden and Julian (1971, 1972, 1994)

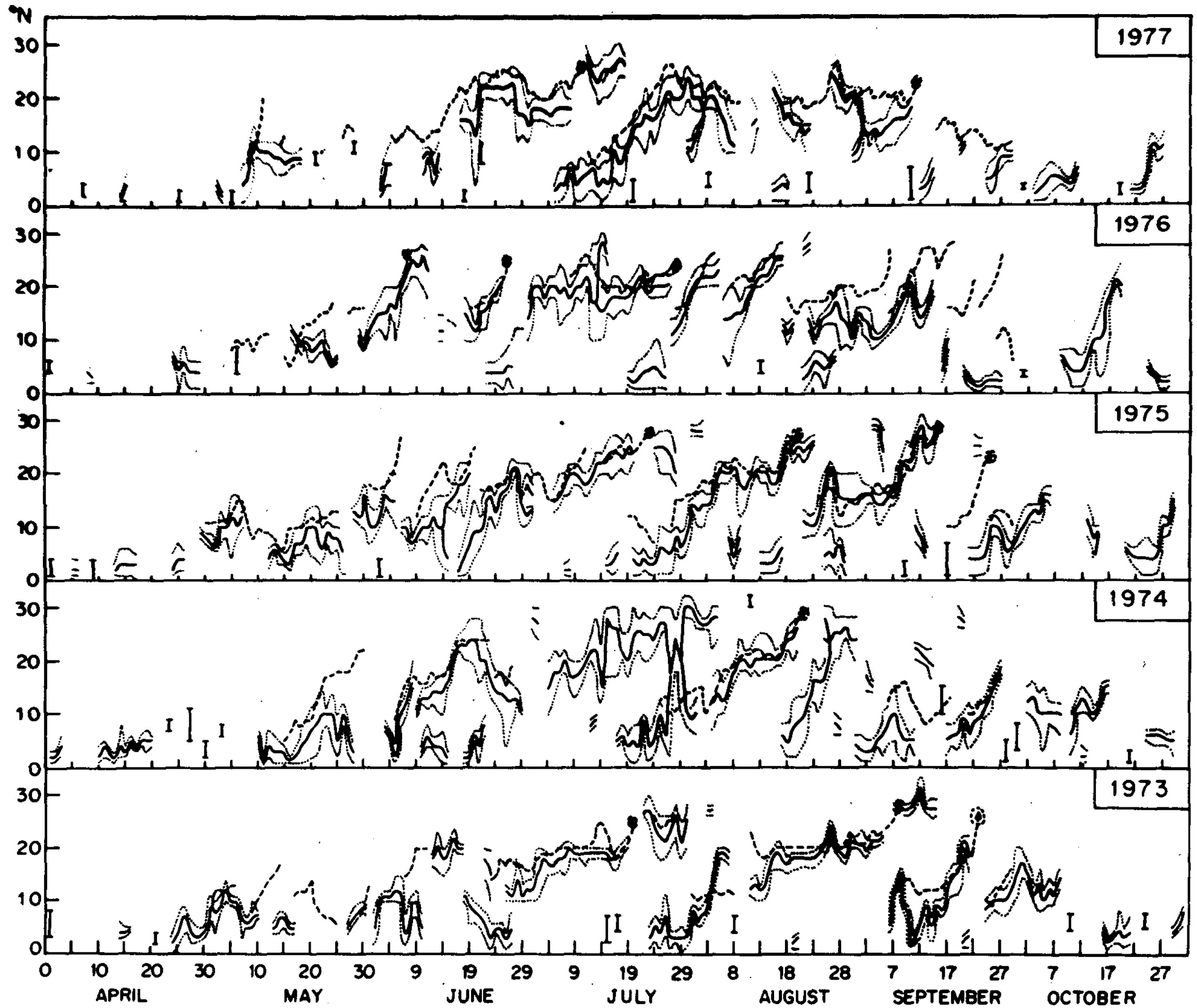
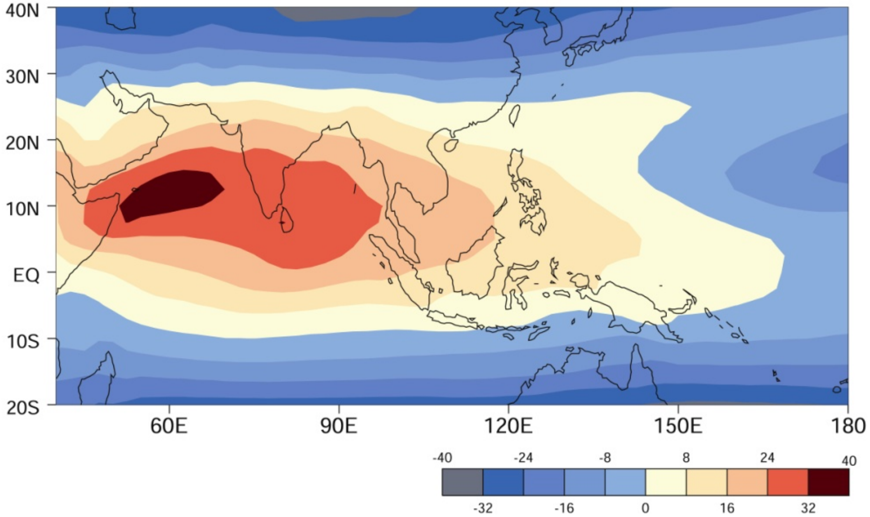


FIG. 4. Daily variation of the latitude of the axis of the MCZ (solid line); northern and southern limits (dotted line) of the MCZ; and the location of the 700 mb trough (dashed line) at 90°E during 1973–77.

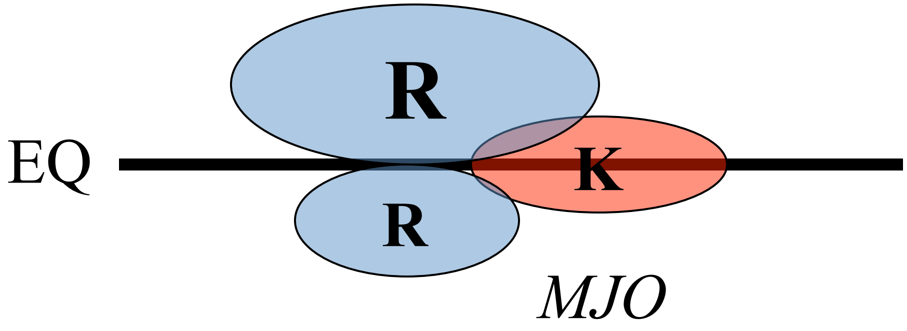
Sikka and Gadgil (1980)

Mean Monsoon and Intraseasonal Variability

Zonal Vertical Shear



Lau and Peng (1990)
Wang and Xie (1997)
Annamalai and Sperber (2005)



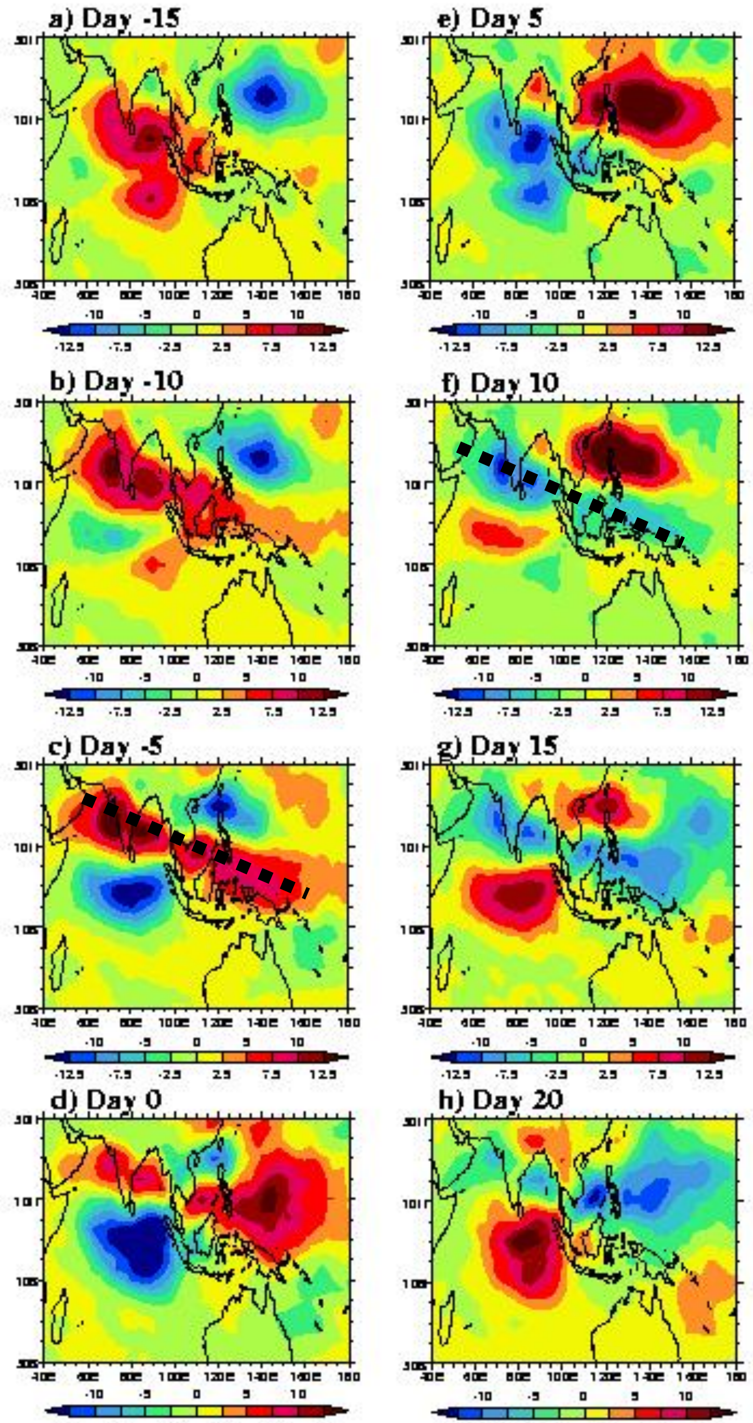
Rossby-Kelvin packet

Initiation

Annamalai and Sperber (2005)

“tilted rain band”

Amplification



Poleward - India

Eastward – W. Pacific

Poleward – W. Pacific

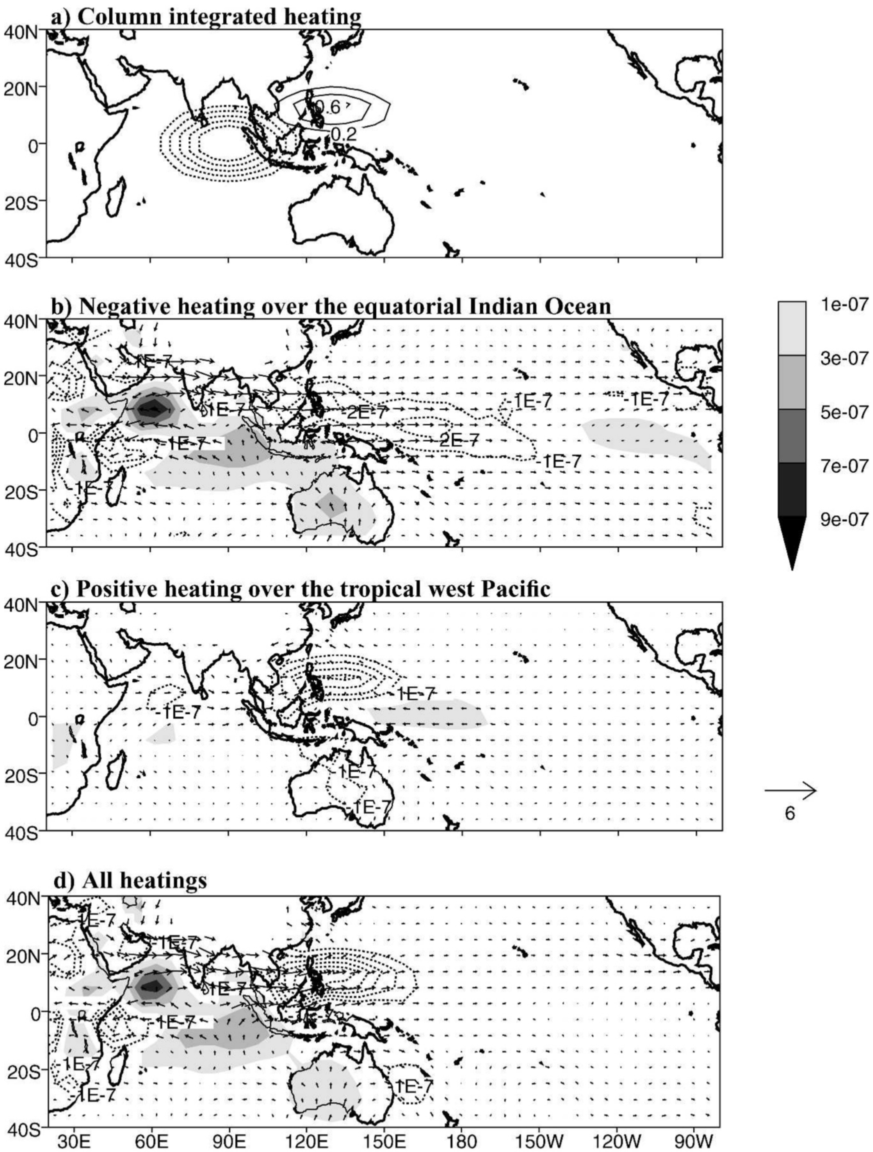


FIG. 6. Day −15 (a) column integrated heating anomalies (K day^{-1}), steady-state response of 850-hPa wind (m s^{-1}), and divergence (s^{-1}) to day −15 heating: (b) negative heating over the equatorial Indian Ocean, (c) positive heating over the tropical west Pacific, and (d) total response [sum of (b) and (c)].

Prescribed heating

850 hPa wind / divergence

Linear model (Watanabe and Jin 2002)

Annamalai and Sperber 2005

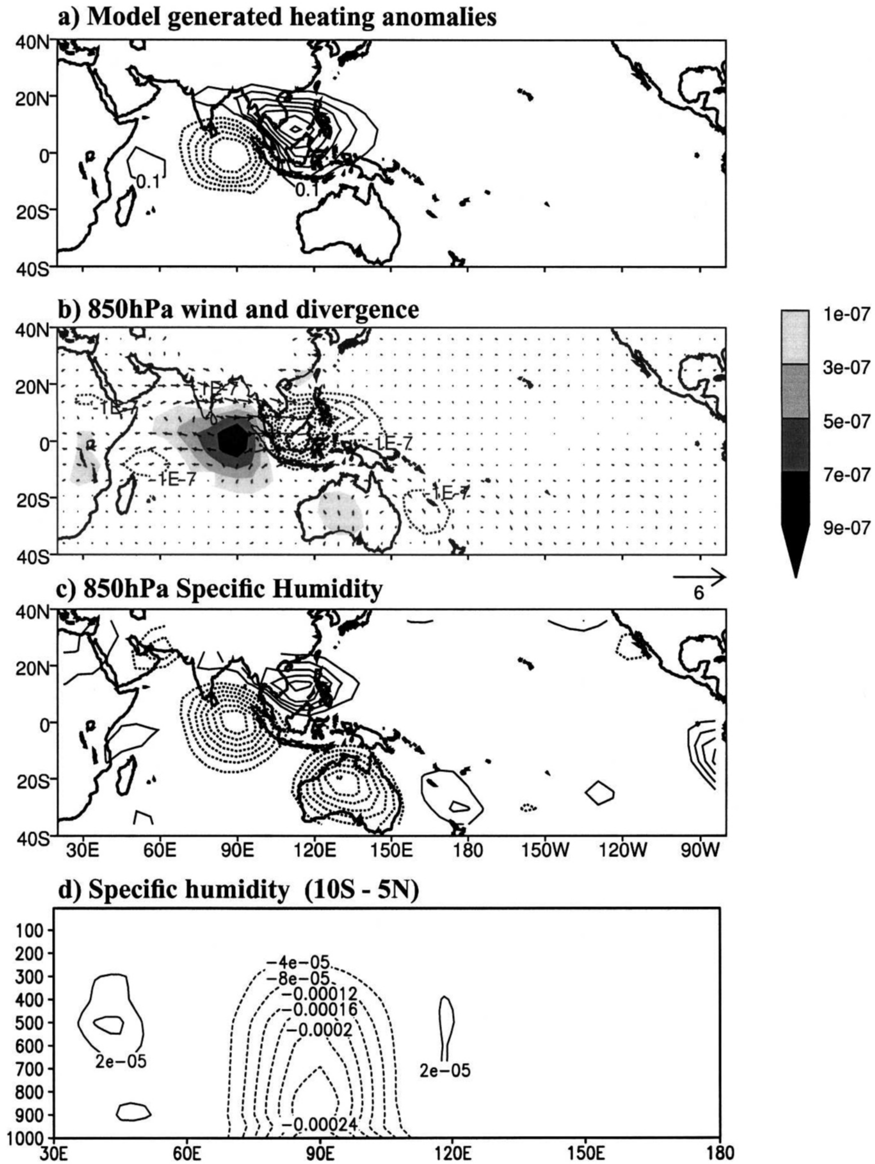
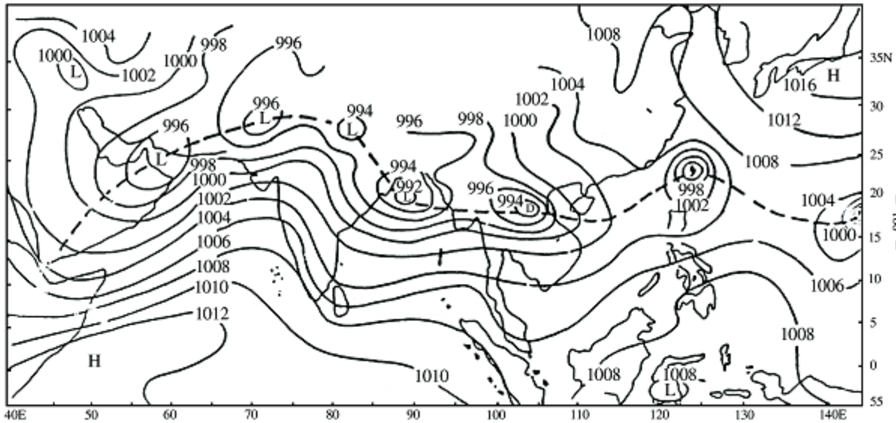


FIG. 7. (a) Model-generated heating anomalies (K day^{-1}) for prescribed cold SST anomalies over the equatorial Indian Ocean, (b) steady-state response of 850-hPa wind (m s^{-1}) and divergence (s^{-1}), (c) 850-hPa specific humidity (kg kg^{-1}), and (d) specific humidity averaged over 10°S–5°N from 1000 to 100 hPa. The negative (positive) contour interval is 0.2 (0.1) K day^{-1} in (a) and is dashed (solid). The negative contour interval in (b) is 1.0 e^{-07} and the positive values are shaded progressively. The contour interval for positive (negative) values is 2×10^{-5} (4×10^{-5}) in (c)–(d).

Model-generated heating

Annamalai and Sperber 2005

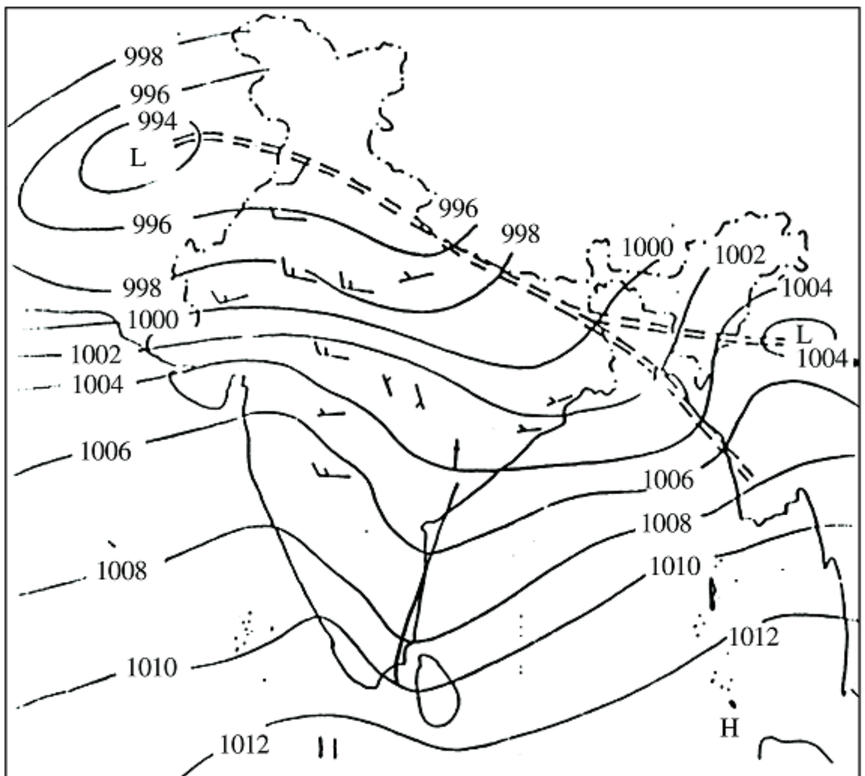
Active Phase



(a)

"favorable for successive genesis of lows/depressions"

Break Phase

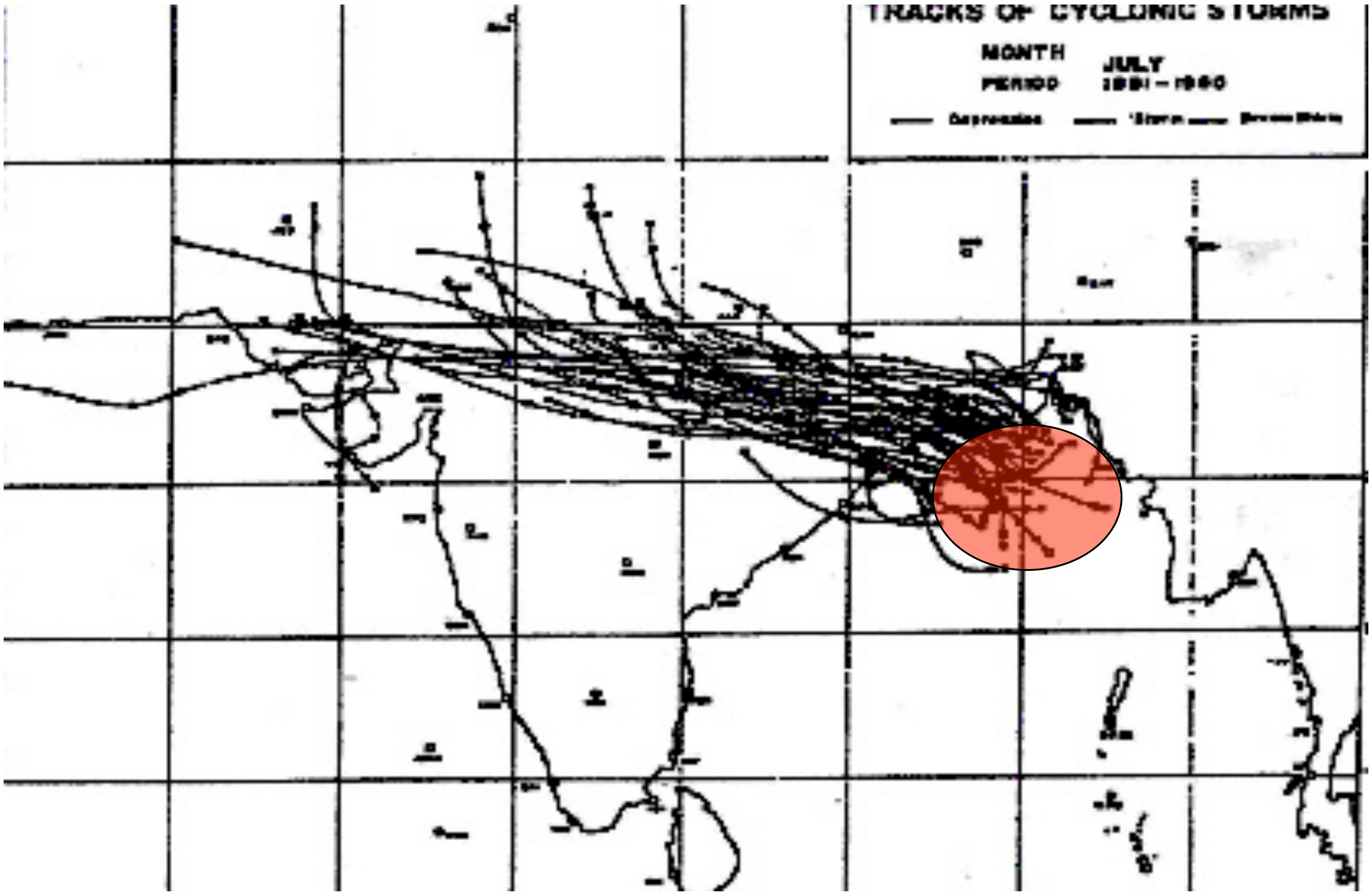


(b)

"foot hills of the Himalayas lead to floods in the rivers"

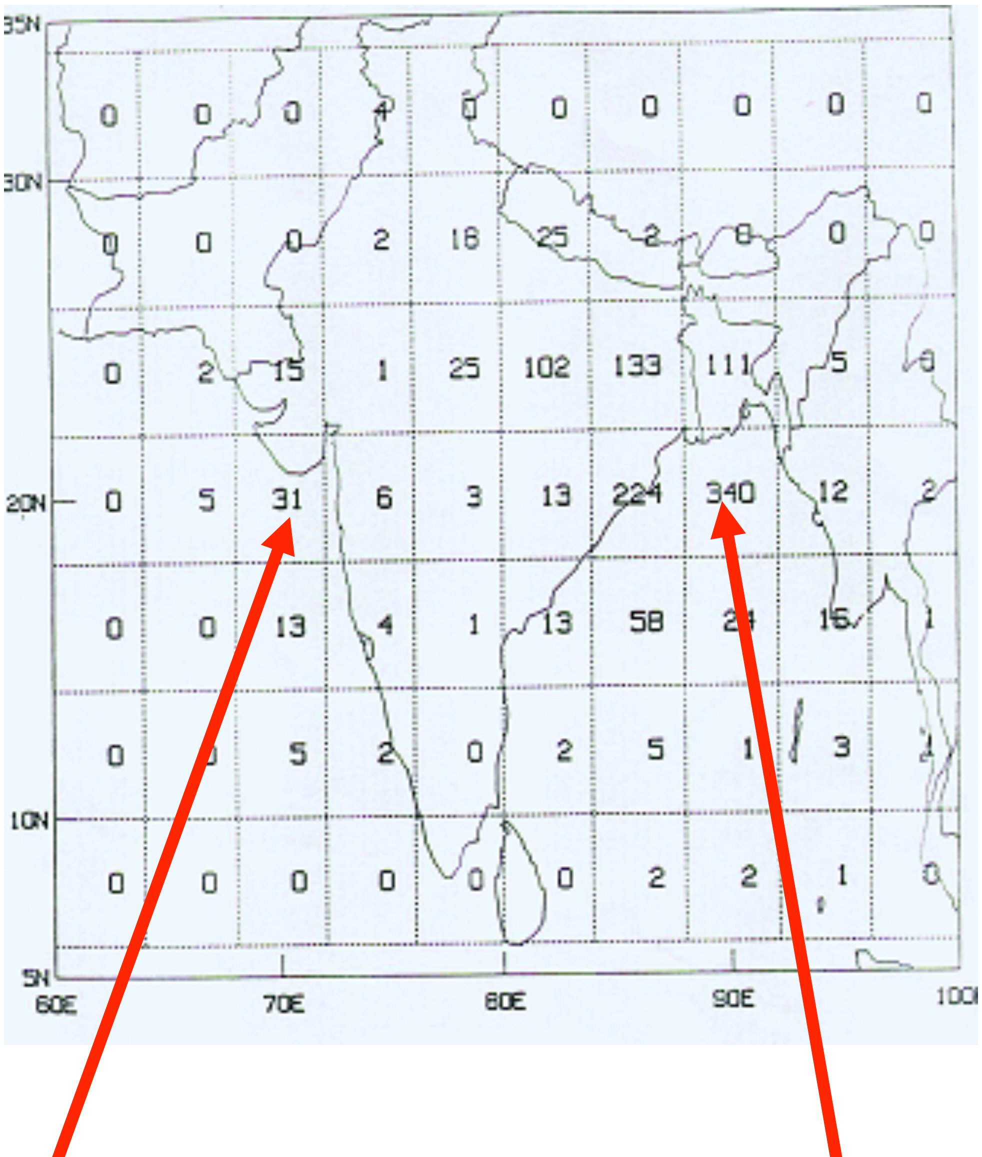
"in both cases, some regions over India face flood situations"

Mean Monsoon and Synoptic Systems



Role of the basic flow

Number of lows and depressions



Monsoon lows and depressions

Number of low-pressure systems (lows, depressions, and cyclonic storms) which formed over 4º lat/long blocks over the south Asian region in the summer monsoon season during 1888-1983

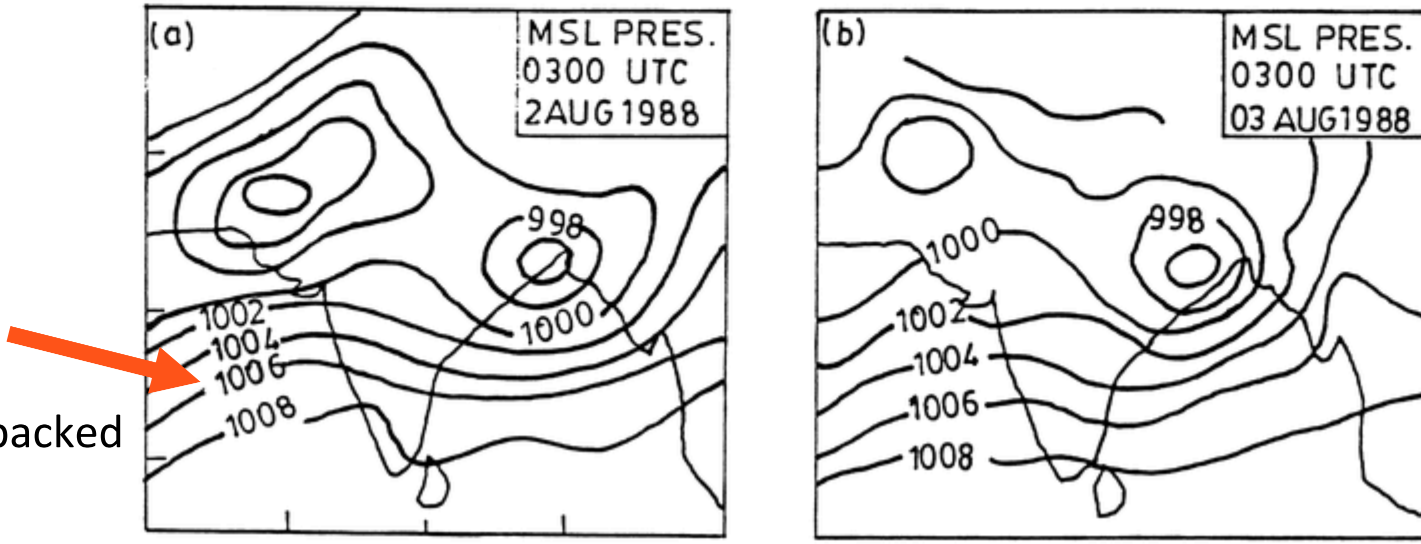
Main features:

Maximum numbers of low-pressure systems form over the northern Bay of Bengal.

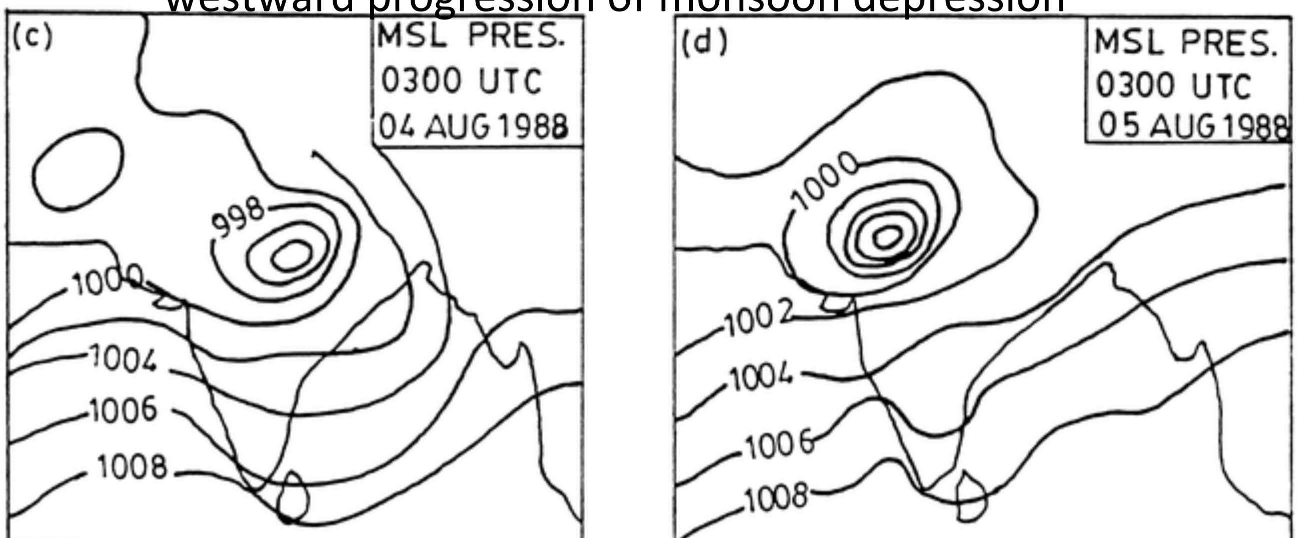
Climatologically, 7 depressions and 1.5 cyclonic storms form over the Bangladesh-India-Pakistan region.

Mean: 13 Standard deviation: 2.2

“closey packed Isobars”



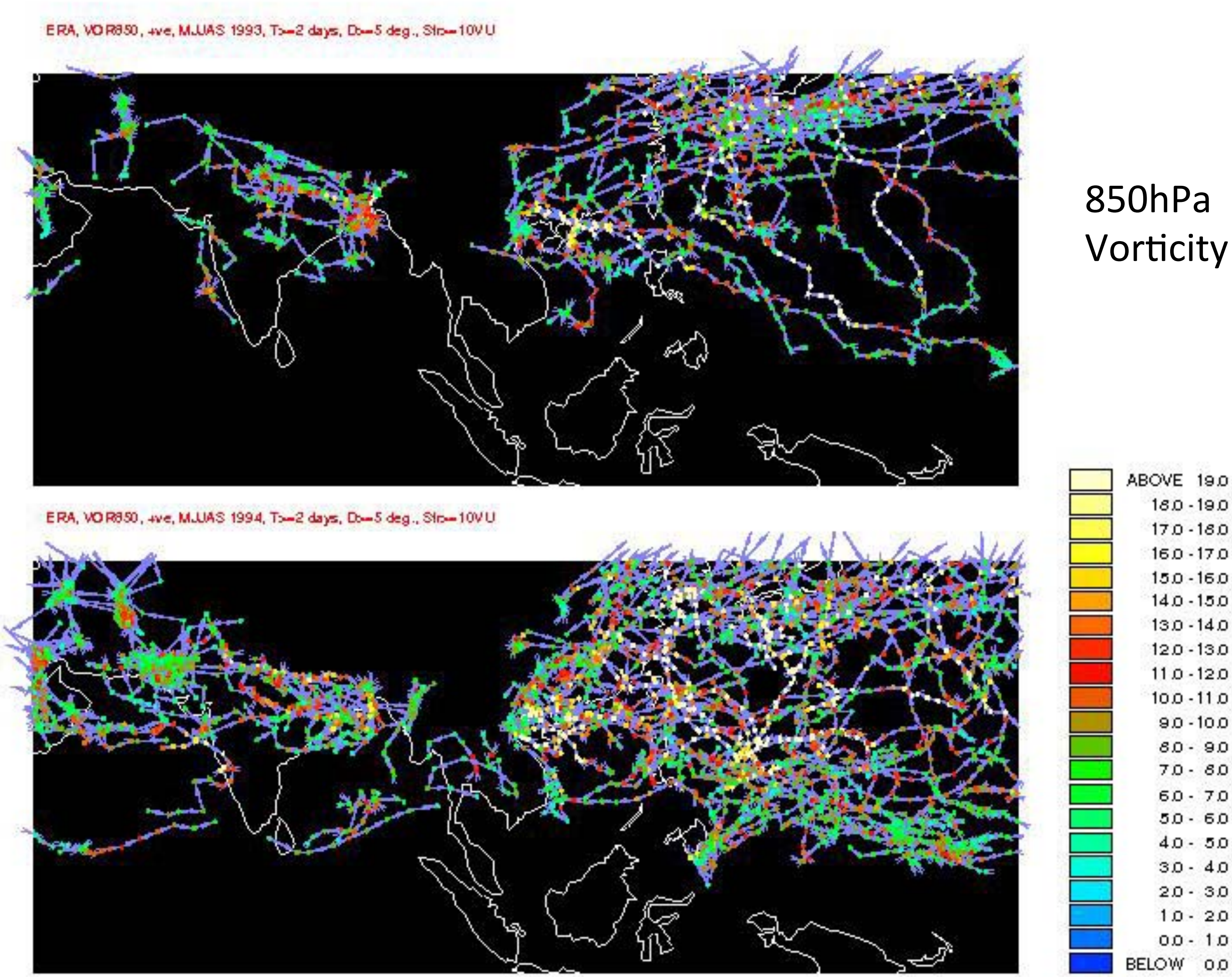
“westward progression of monsoon depression”



“westward progression of a monsoon depression – vorticity budget – divergence term
- Maximum rainfall SW quadrant - Rossby waves – east-west divergent circulation”

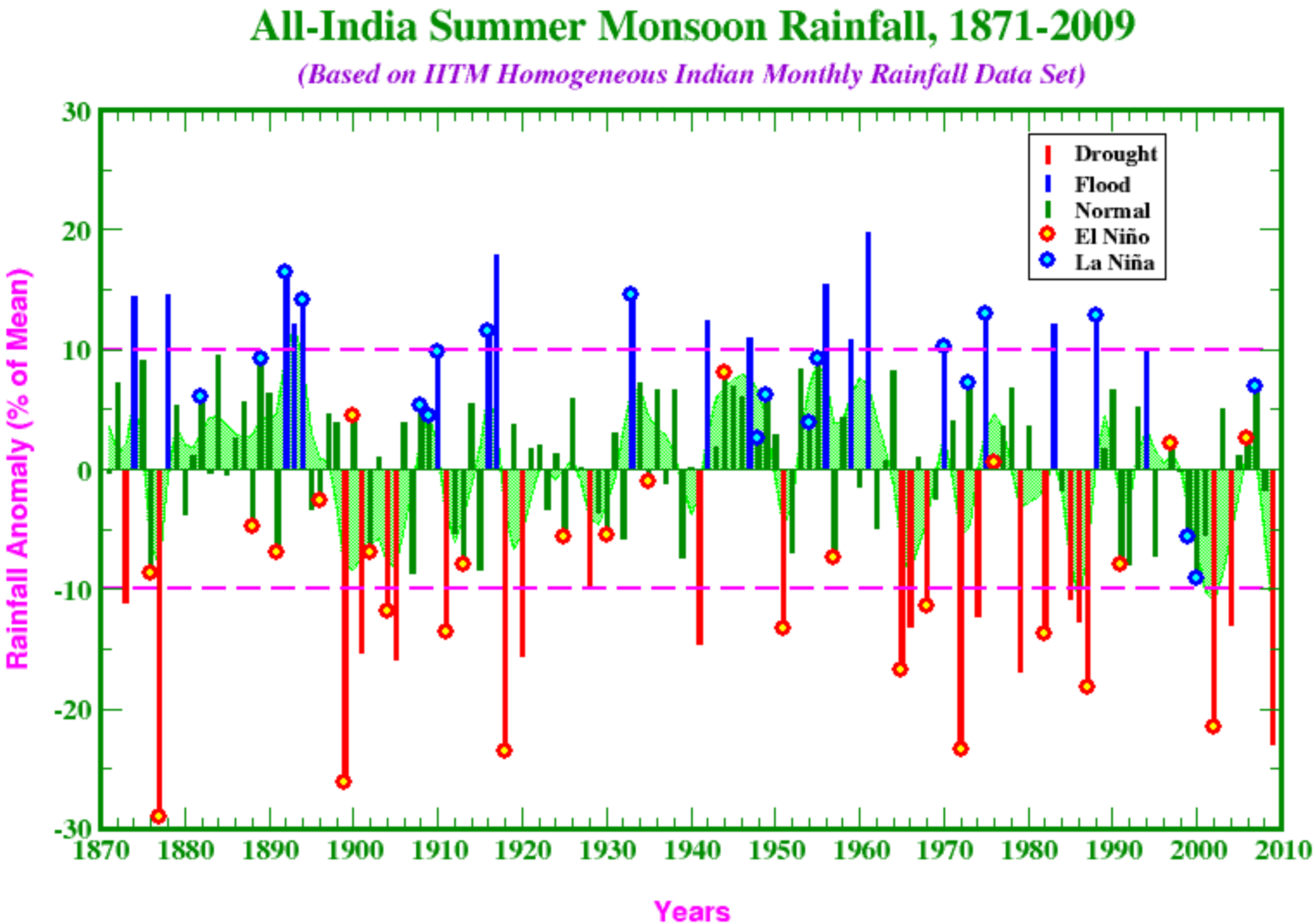
Tracks of Synoptic Systems (1993 – Boreal summer)

850hPa Vorticity



Strong – Indian and West Pacific monsoon

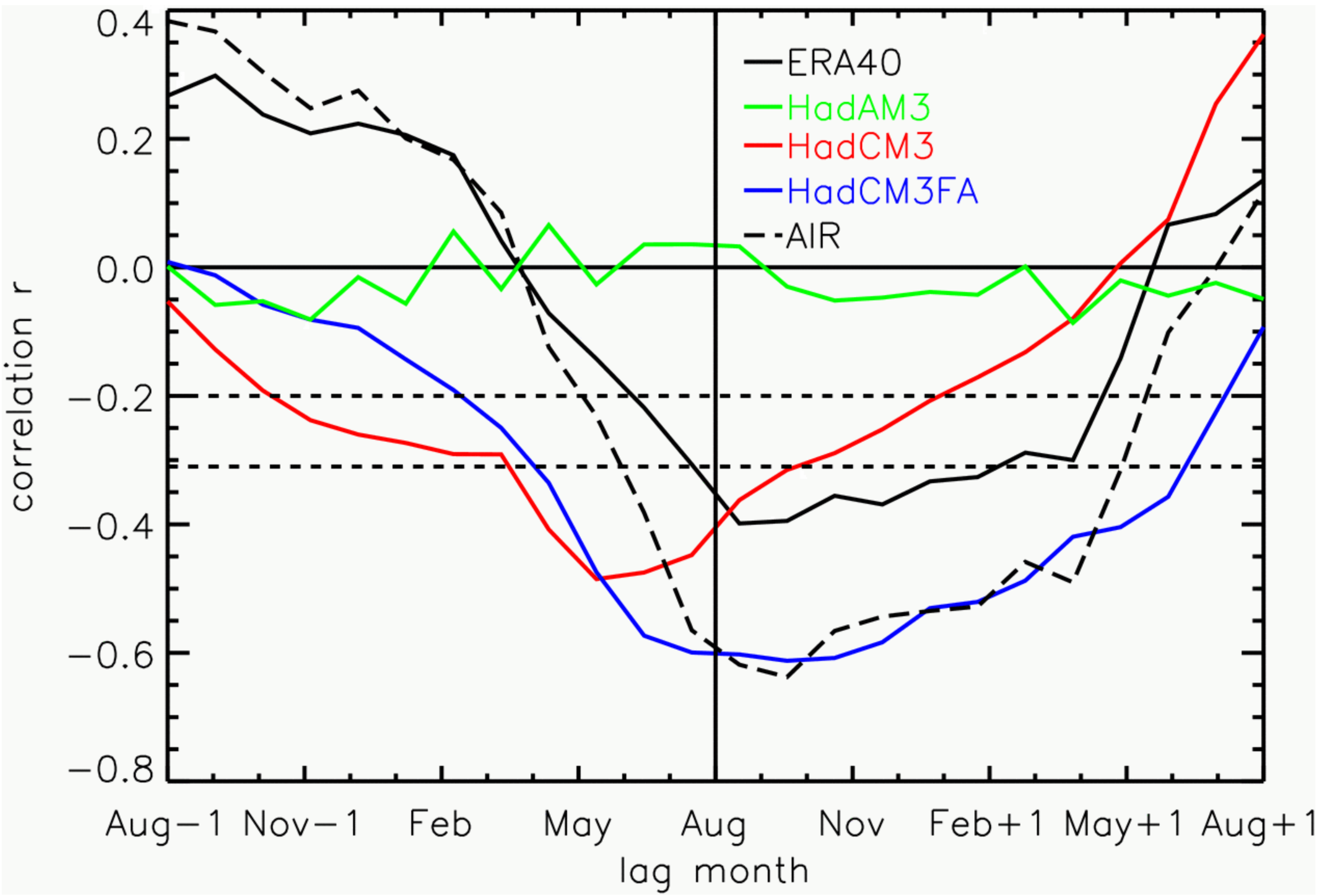
Tracks of Synoptic Systems (1994 - Boreal summer)



Severe weak monsoon years – associated with El Nino

ENSO-Monsoon Teleconnections

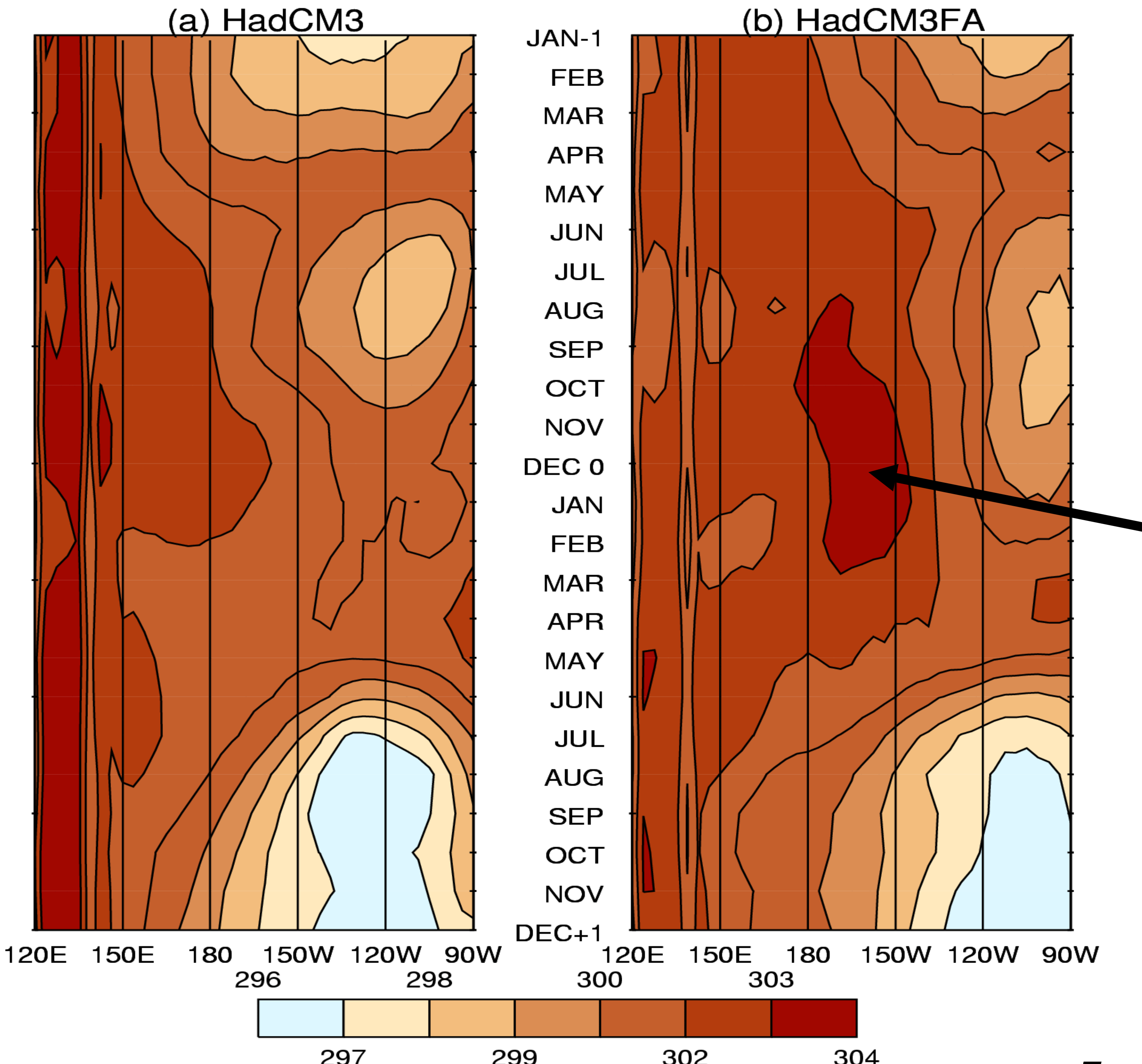
Summer All India Rainfall (AIR) lag-correlated with Nino-3 SSTs



"highlights the role of the basic state"

Turner et al. 2005, QJRMS

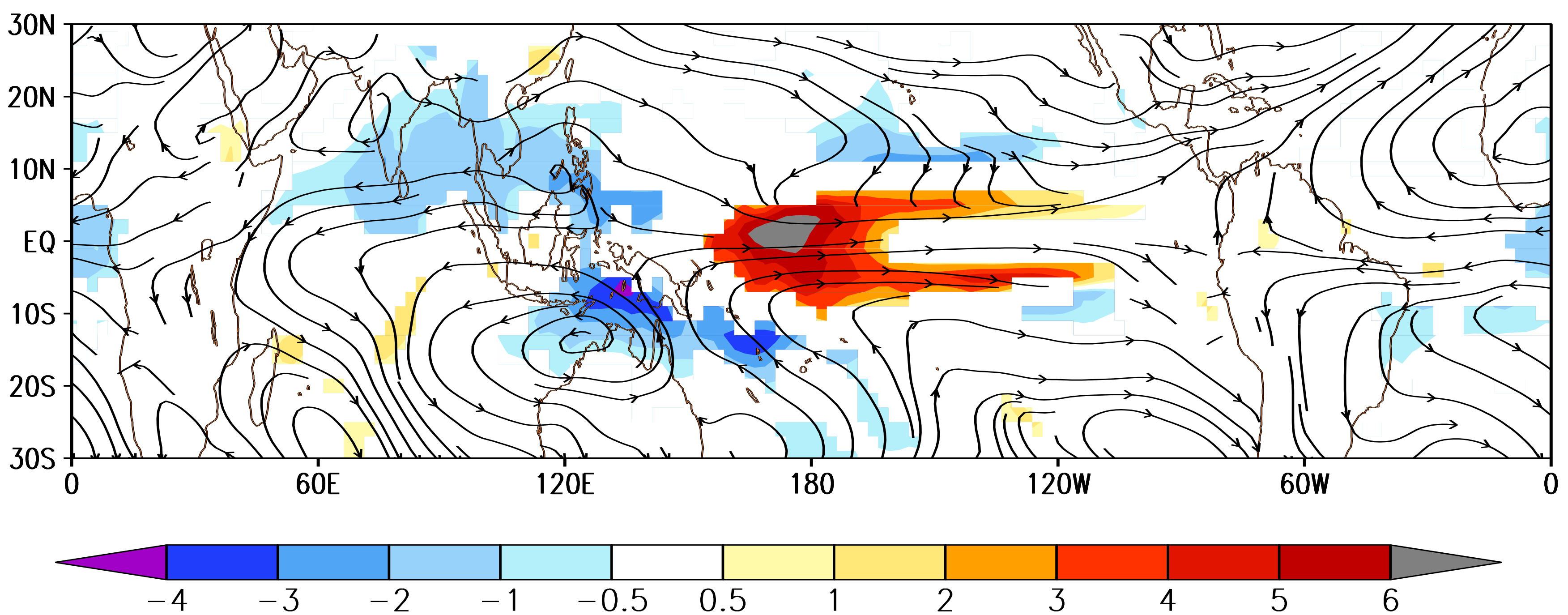
Evolution of SST through composite El Nino



Note that warmest water moves into the central Pacific with improved basic state

Turner et al. 2005, QJRMS

May averaged CM2.1 composite of anomalous 850 hPa stream line and rainfall



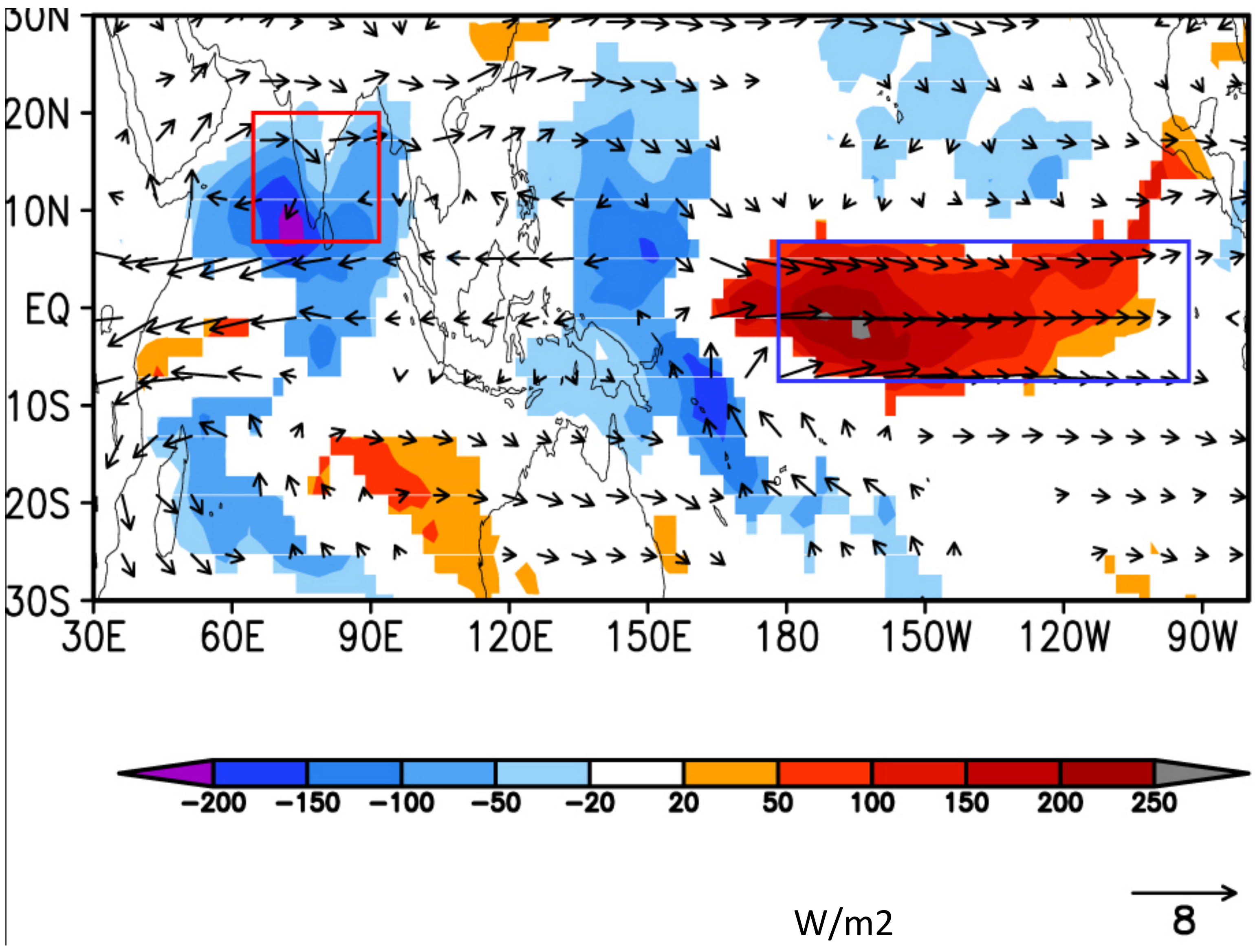
Severe weak monsoons over south Asia co-occurred with developing phase of El Nino

NIO – anticyclonic vorticity – within 2-3 days of SST forcing – rainfall after about 20 days

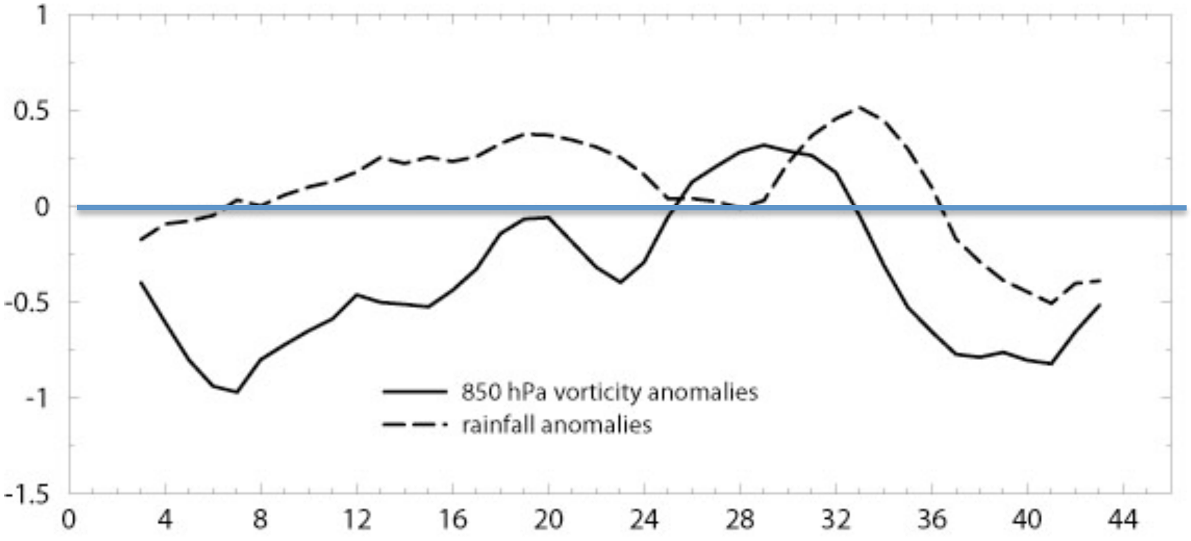
Dry air advection from north is instrumental in initiating the dryness

Pillai and Annamalai (2012, J. Atmos. Sci.)

May rainfall and 850 hPa wind response to El Nino SST forcing



AM2.1 solutions – Forced with CM2.1 composite SST anomalies (El Nino)

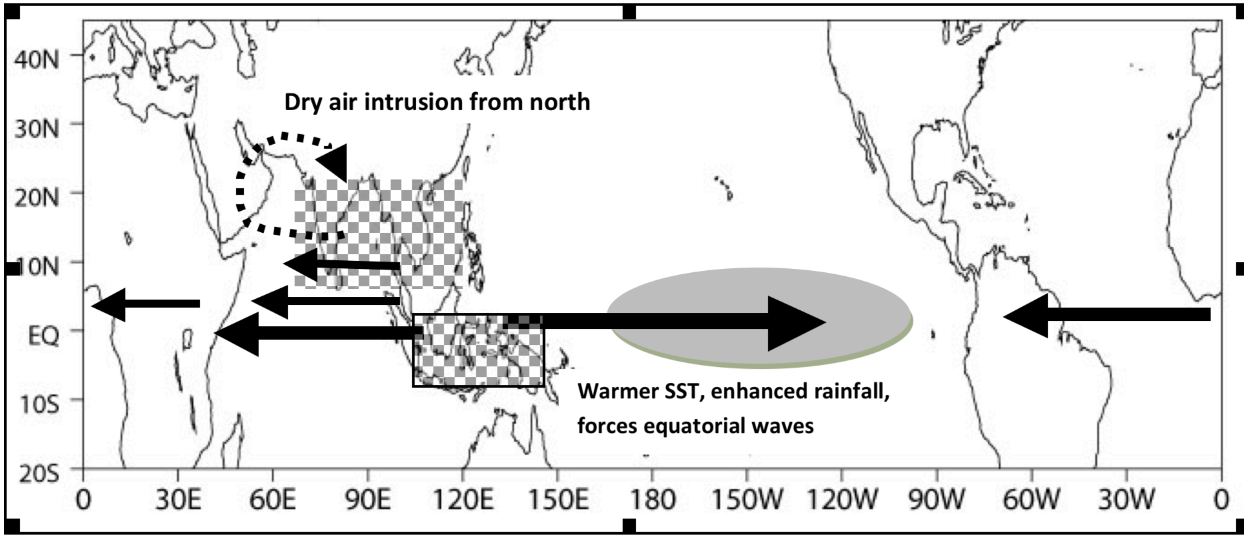


Days from 15 March

Rainfall over S. Asia

850 hPa Vorticity

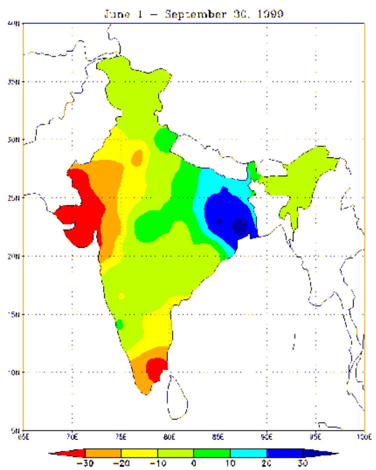
(west of rainfall maximum)



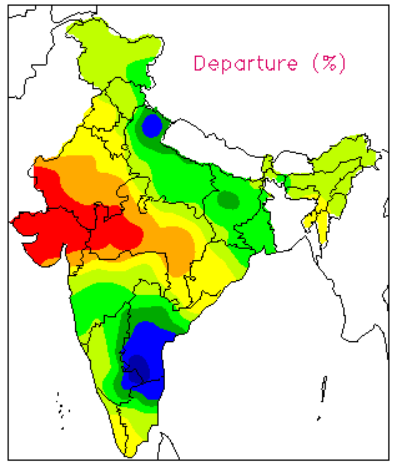
Summary – Case II

“dry advection leads rainfall anomalies – long lead time – useful for prediction”

1999



2000



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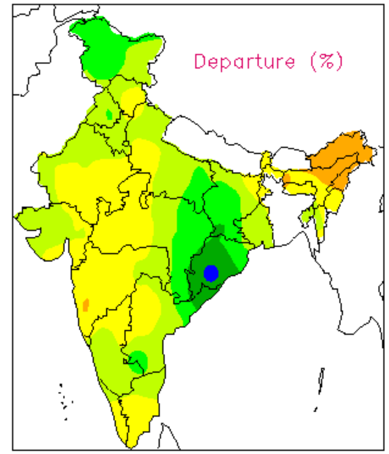

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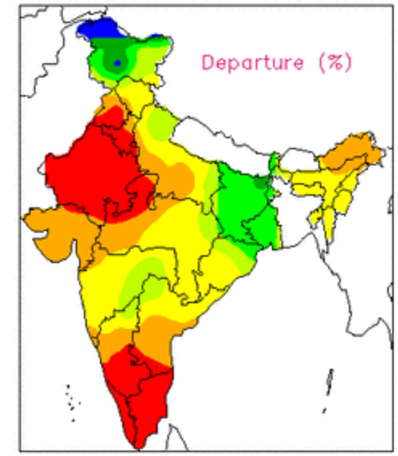
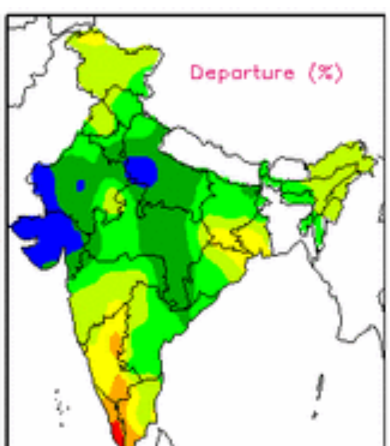


"spatial variation of rainfall anomalies in selected years"

2003



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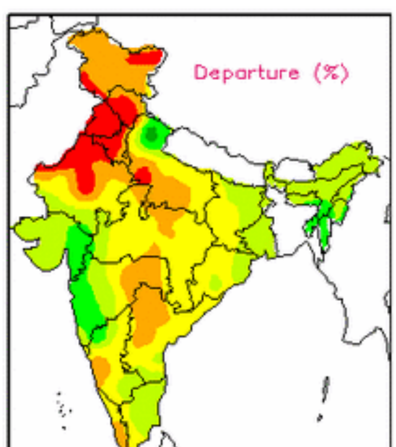

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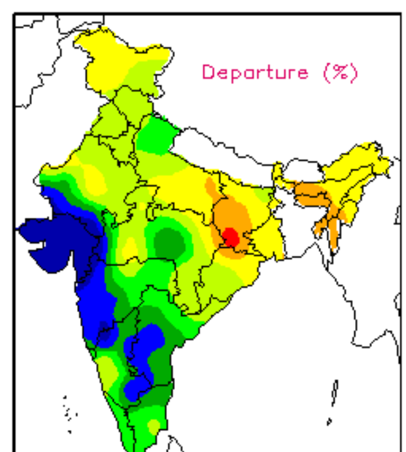
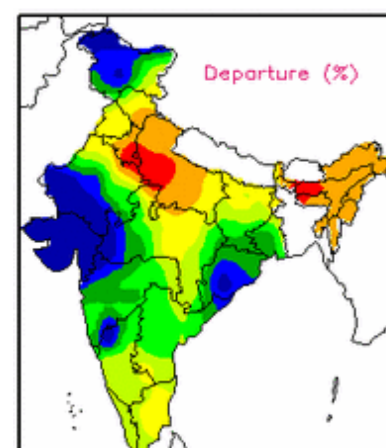


2006



The monsoons: An oceanographer's view …

Shenoi et al (2002)