Winter School, INCOIS
Hyderabad
17 November 2016

Impact of the North Indian Ocean and the surrounding mountains on the Indian Summer Monsoon

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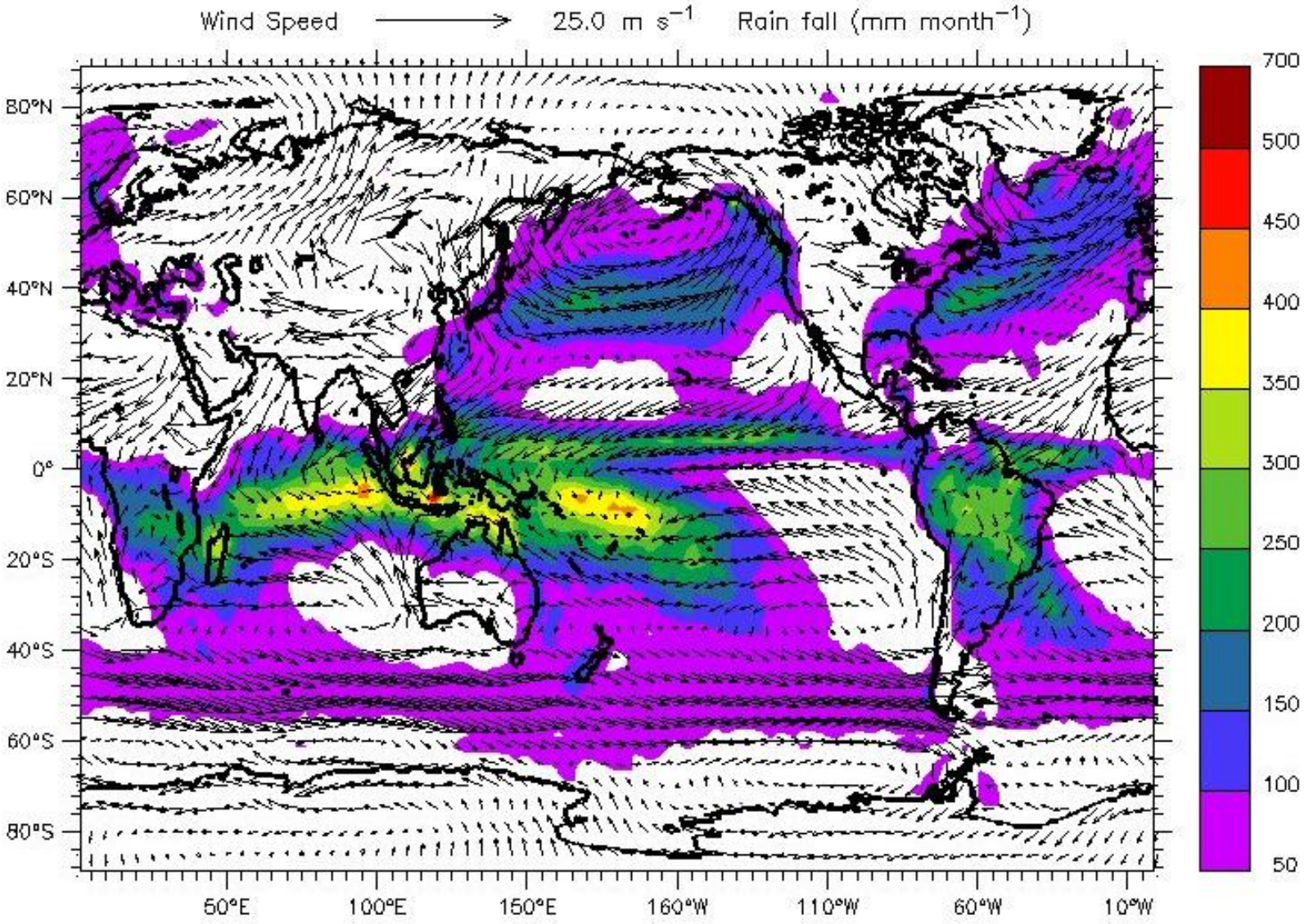
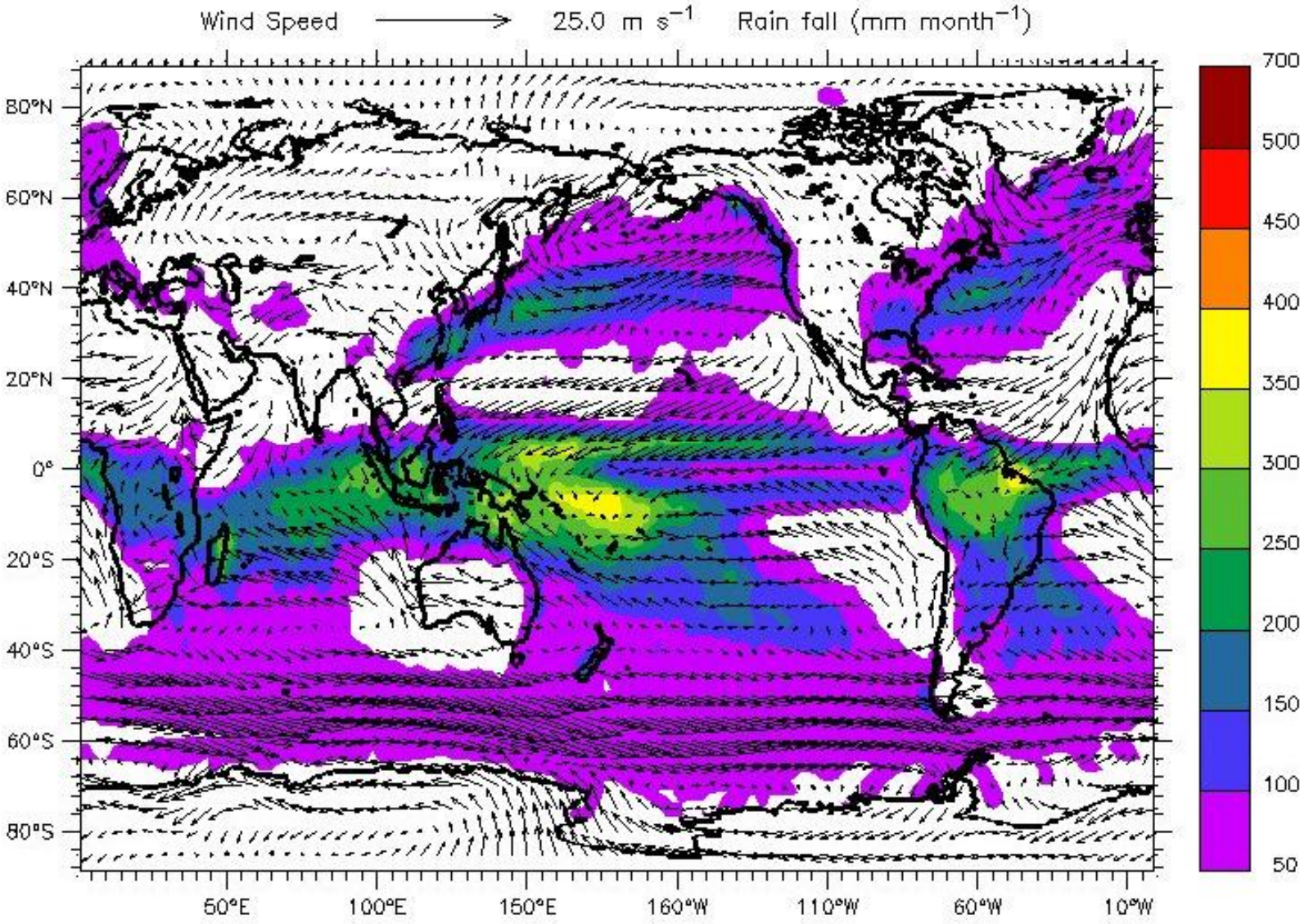
JAN


Wind Speed
25.0 m s^{-1}
Rain fall (mm month^{-1})
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W
700
500
450
400
350
300
250
200
150
100
50

MAR


Wind Speed
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Rain fall (mm month^{-1})
80°N
60°N
40°N
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50°E
100°E
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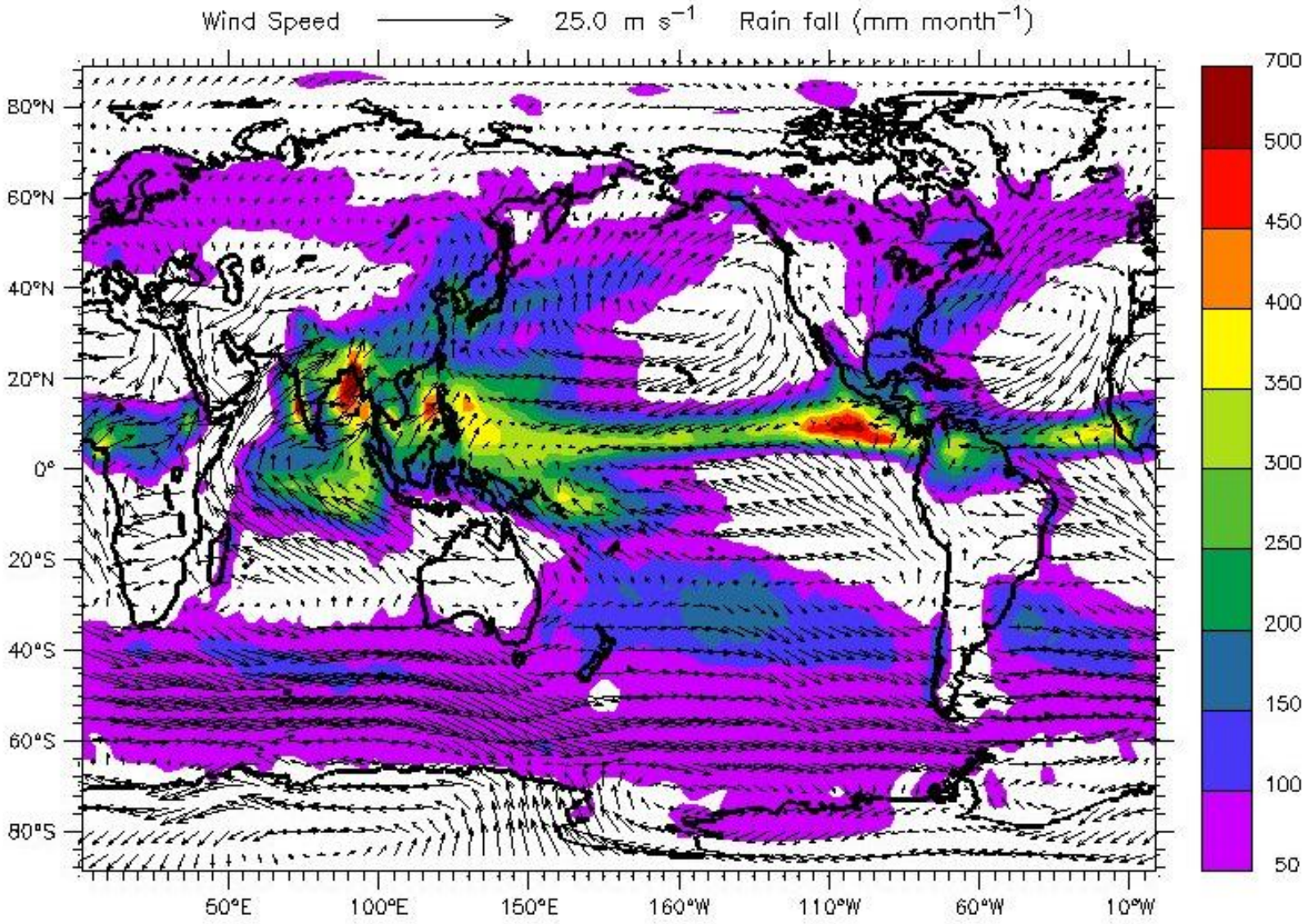
JUL


Wind Speed
25.0 m s^{-1}
Rain fall (mm month^{-1})
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
50°E
100°E
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400
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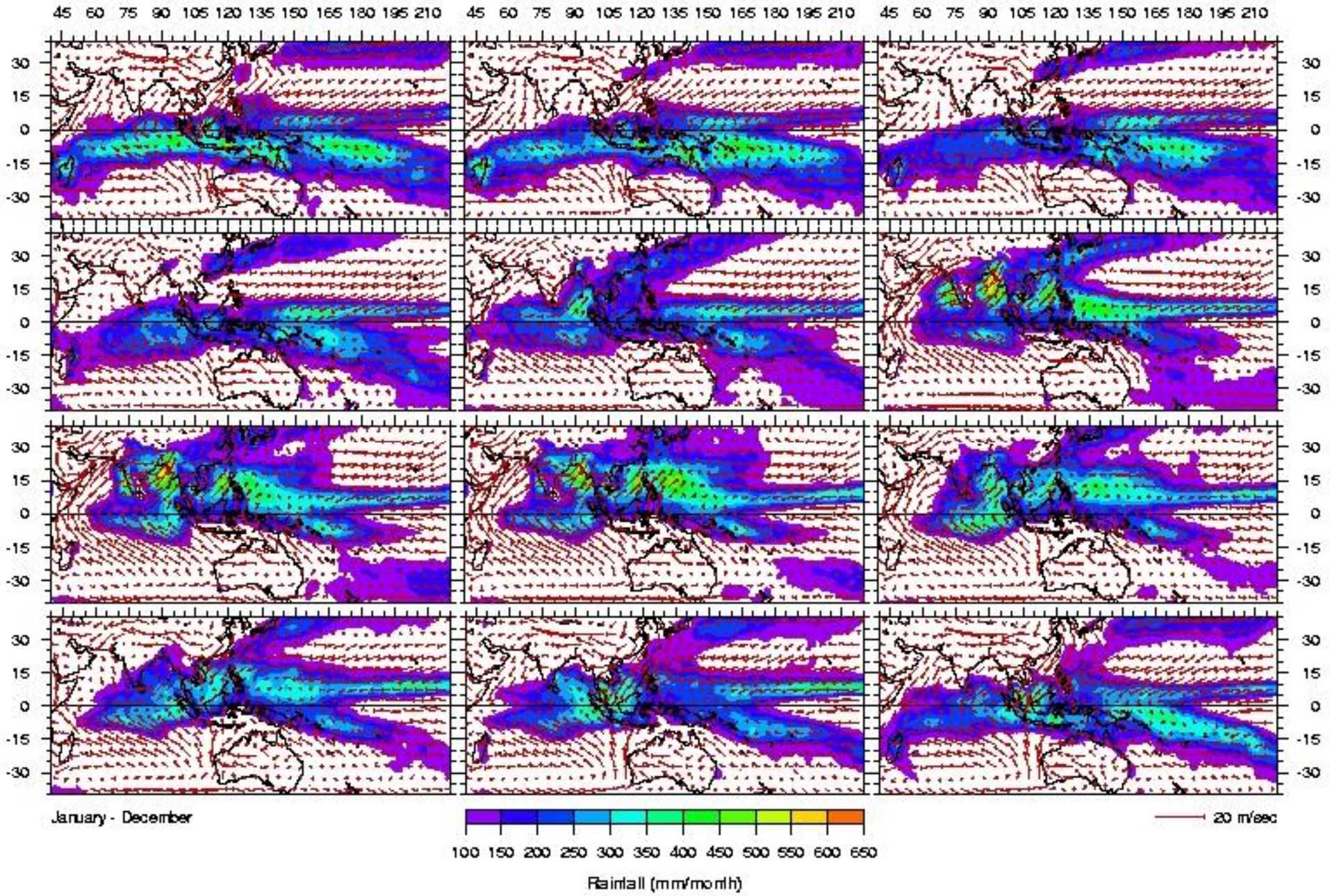
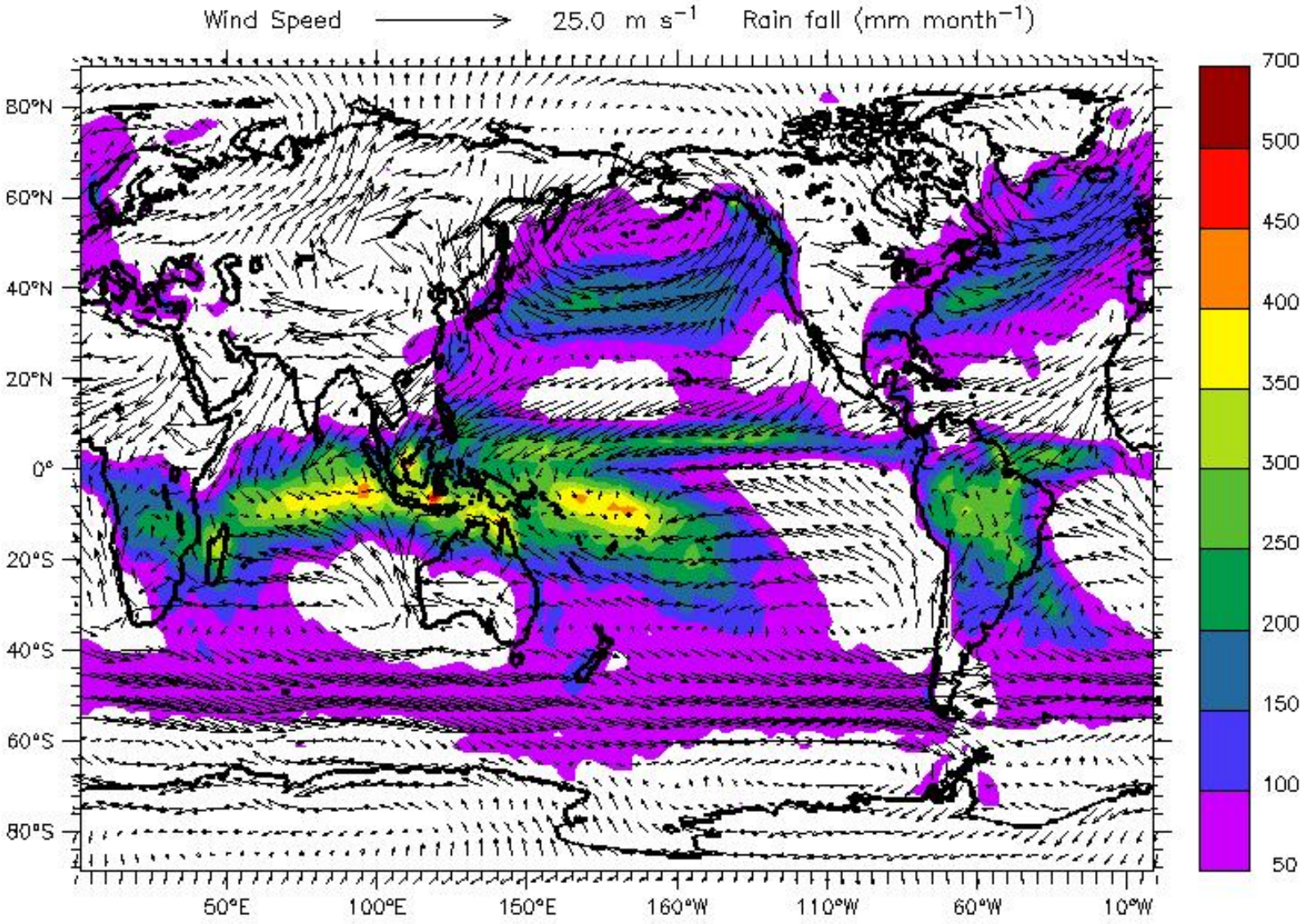

45 60 75 90 105 120 135 150 165 180 195 210
30
15
0
-15
-30
January - December
20 m/sec
100 150 200 250 300 350 400 450 500 550 600 650
Rainfall (mm/month)

JANUARY


Wind Speed
25.0 m s^{-1}
Rain fall (mm month^{-1})
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W
700
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450
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300
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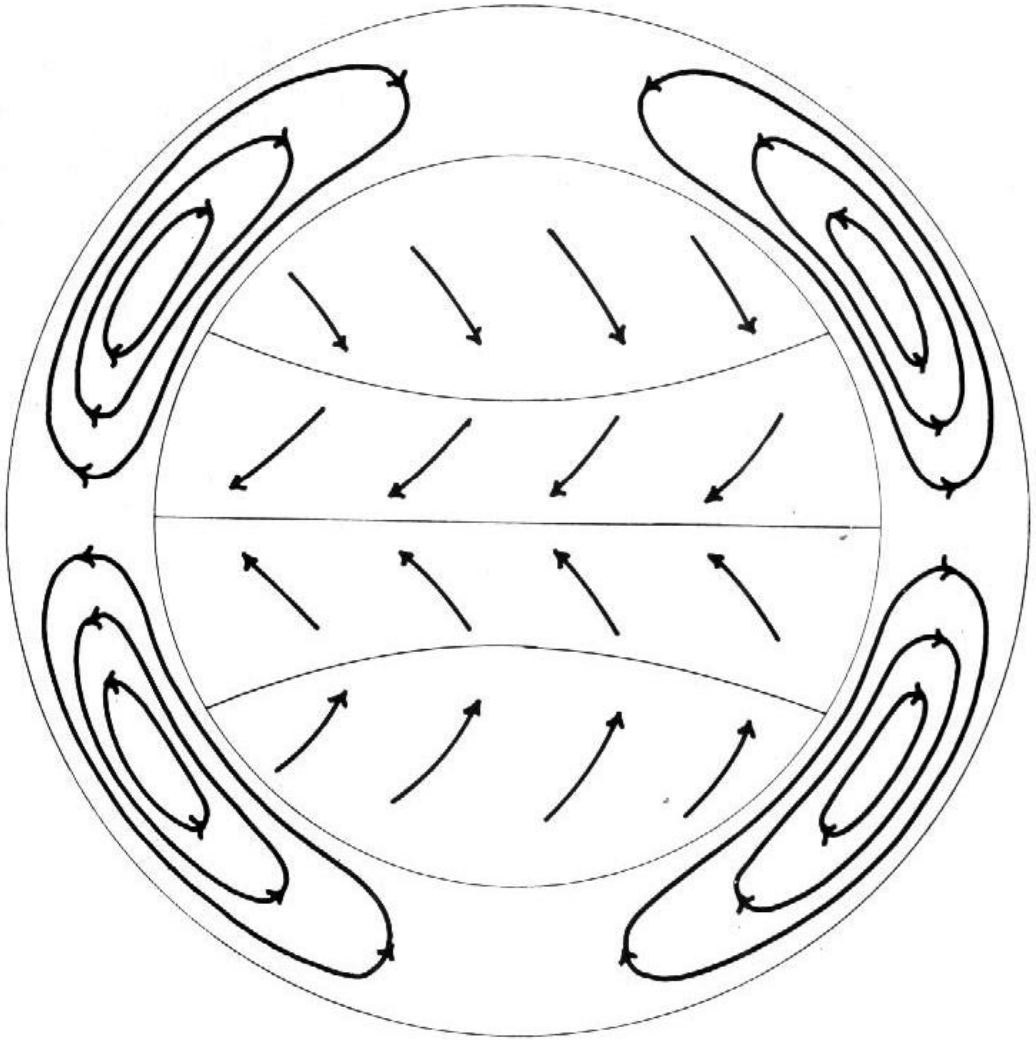
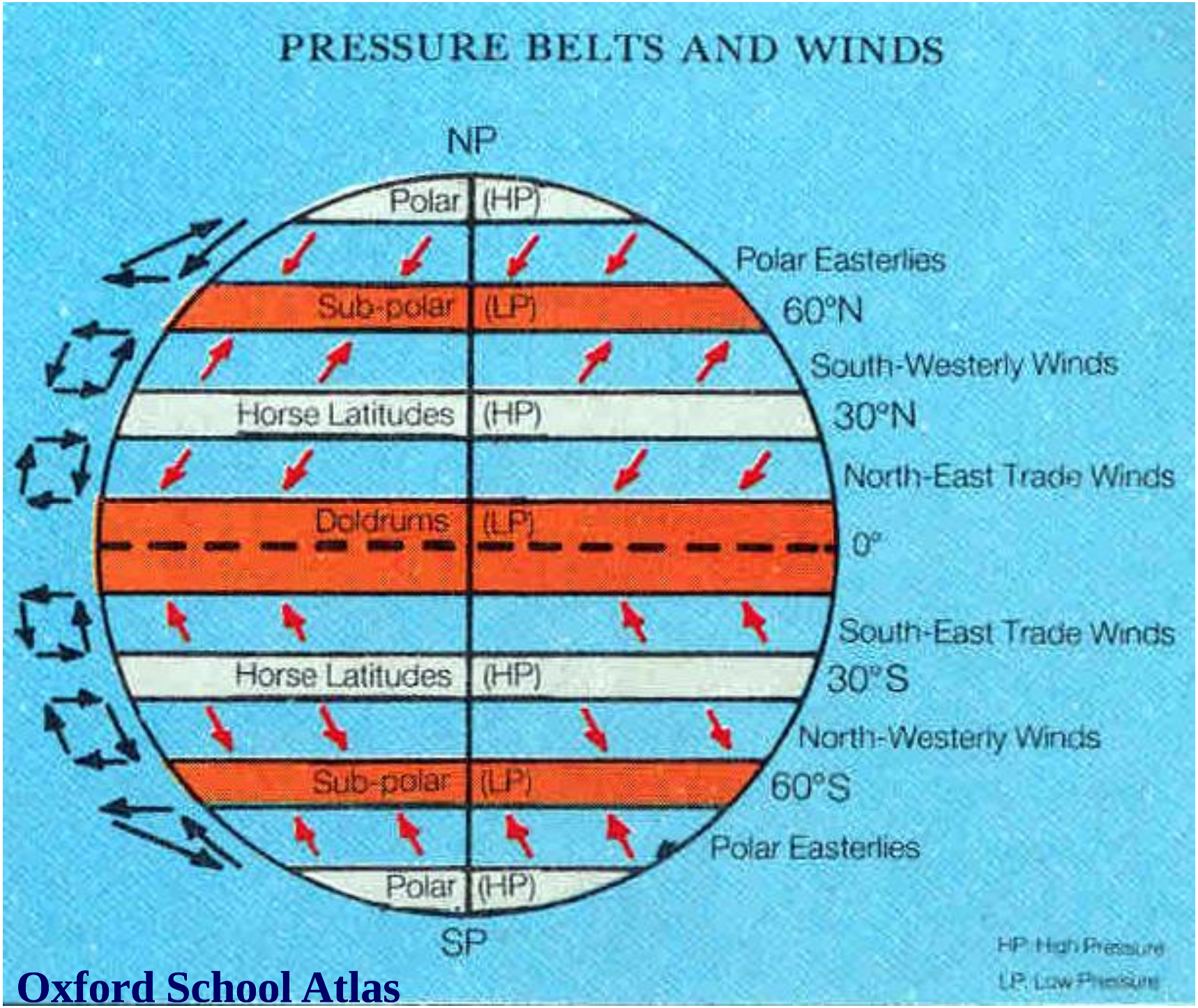
100
50

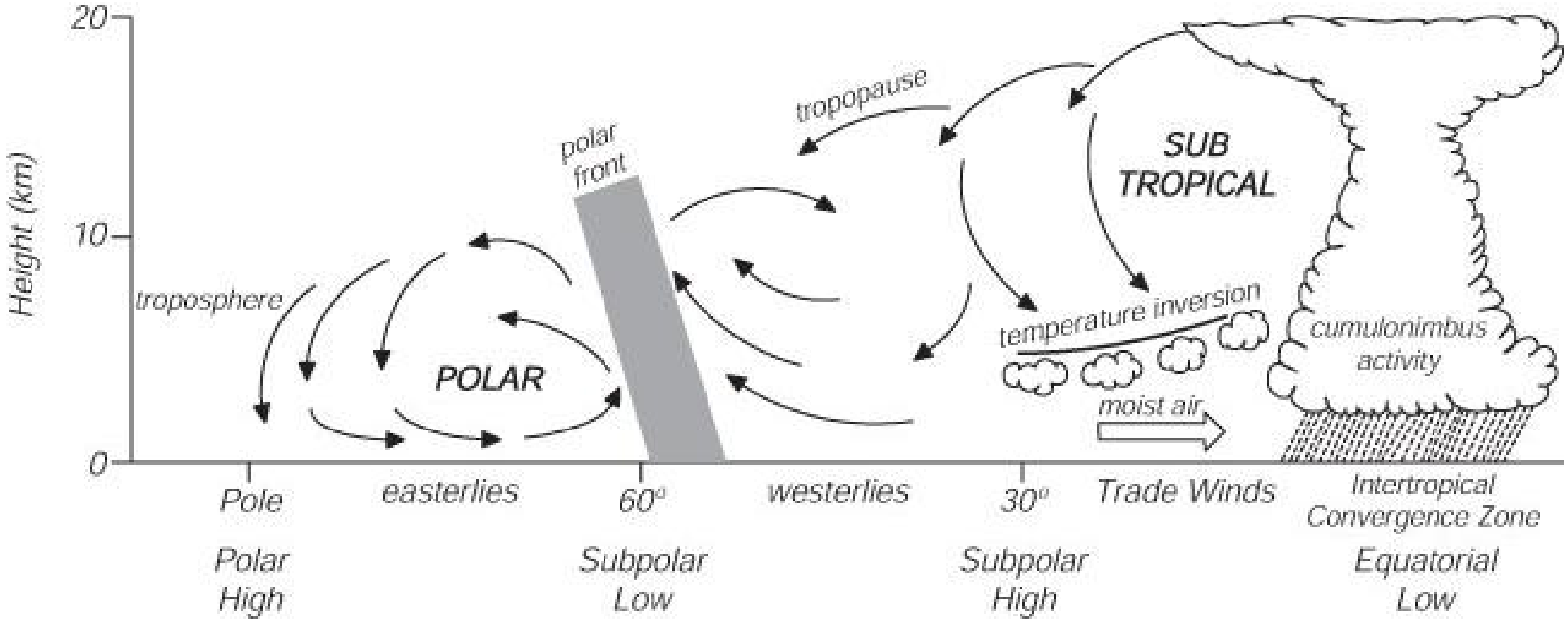
Global circulation according to Hadley (1735)



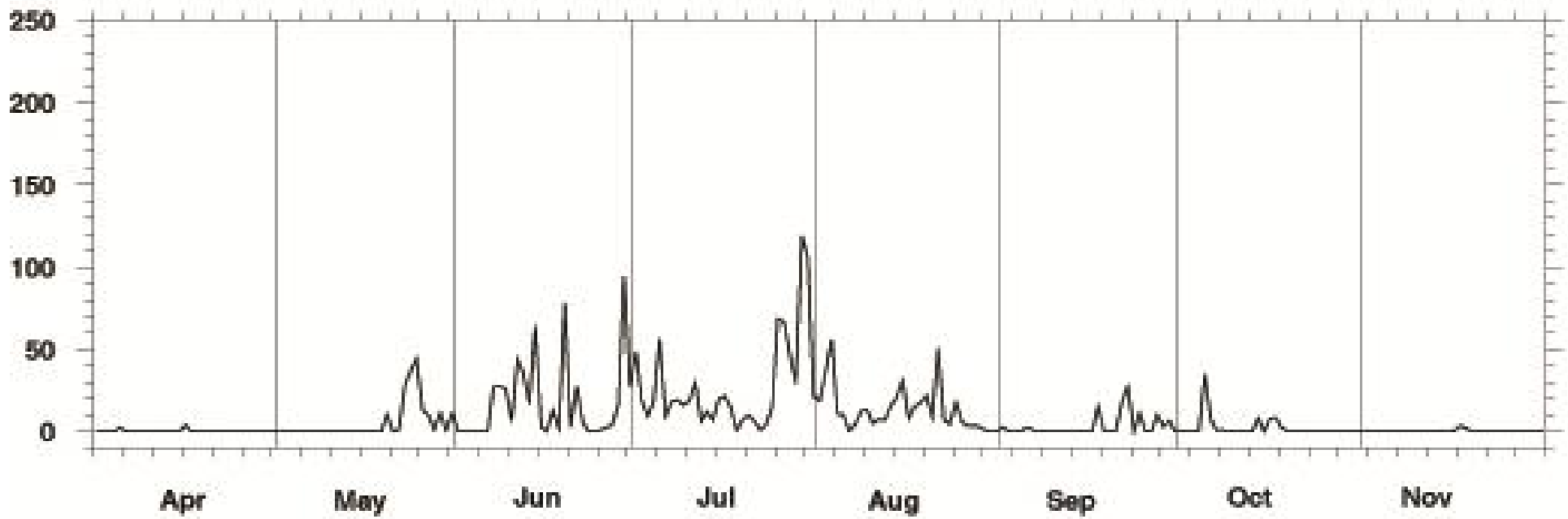
From Lorenz (1967)

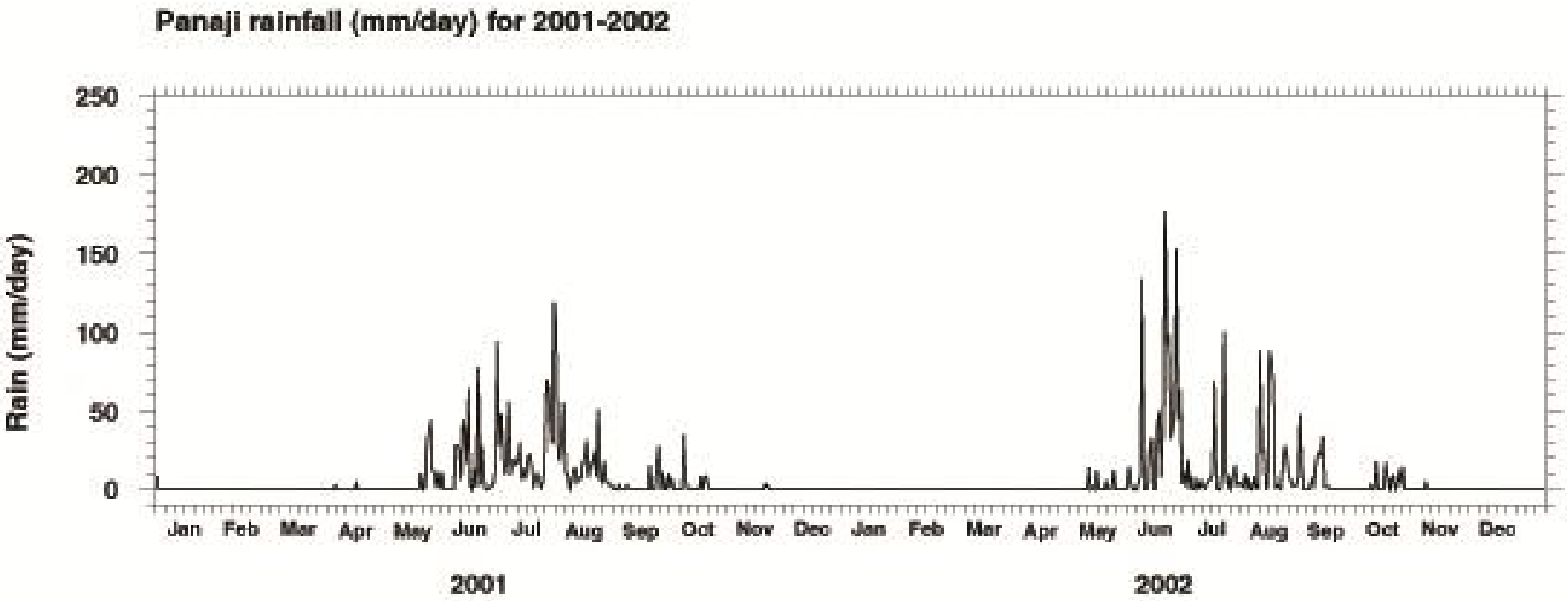


Oxford School Atlas


20
10
0
Height (km)
troposphere
polar front
tropopause
SUB TROPICAL
POLAR
temperature inversion
cumulonimbus activity
moist air
Pole
easterlies
60°
westerlies
30°
Trade Winds
Intertropical Convergence Zone
Polar High
Subpolar Low
Subpolar High
Equatorial Low

Panaji rainfall (mm/day) for April-November 2001




Panaji rainfall (mm/day) for 2001-2002
Rain (mm/day)
250
200
150
100
50
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2001
2002

Some important questions:

1) What causes the precipitation high in the eastern Bay of Bengal and along the central west coast of India?

2) What causes the strong flow in the western Arabian Sea?

3) Why is there a break in the precipitation belt over the western Arabian Sea?

4) What is the role of Himalayan mountains (~8 km high) and Tibetan Plateau (~4.5 km high, 2.5 million sq. km area)?

What causes the precipitation high in the eastern Bay of Bengal and along the central west coast of India?

In the eastern Bay of Bengal the topographic slope over the Arakan Range.

Along the central west coast it is the topographic slope of the Sahyadris (Western Ghats)

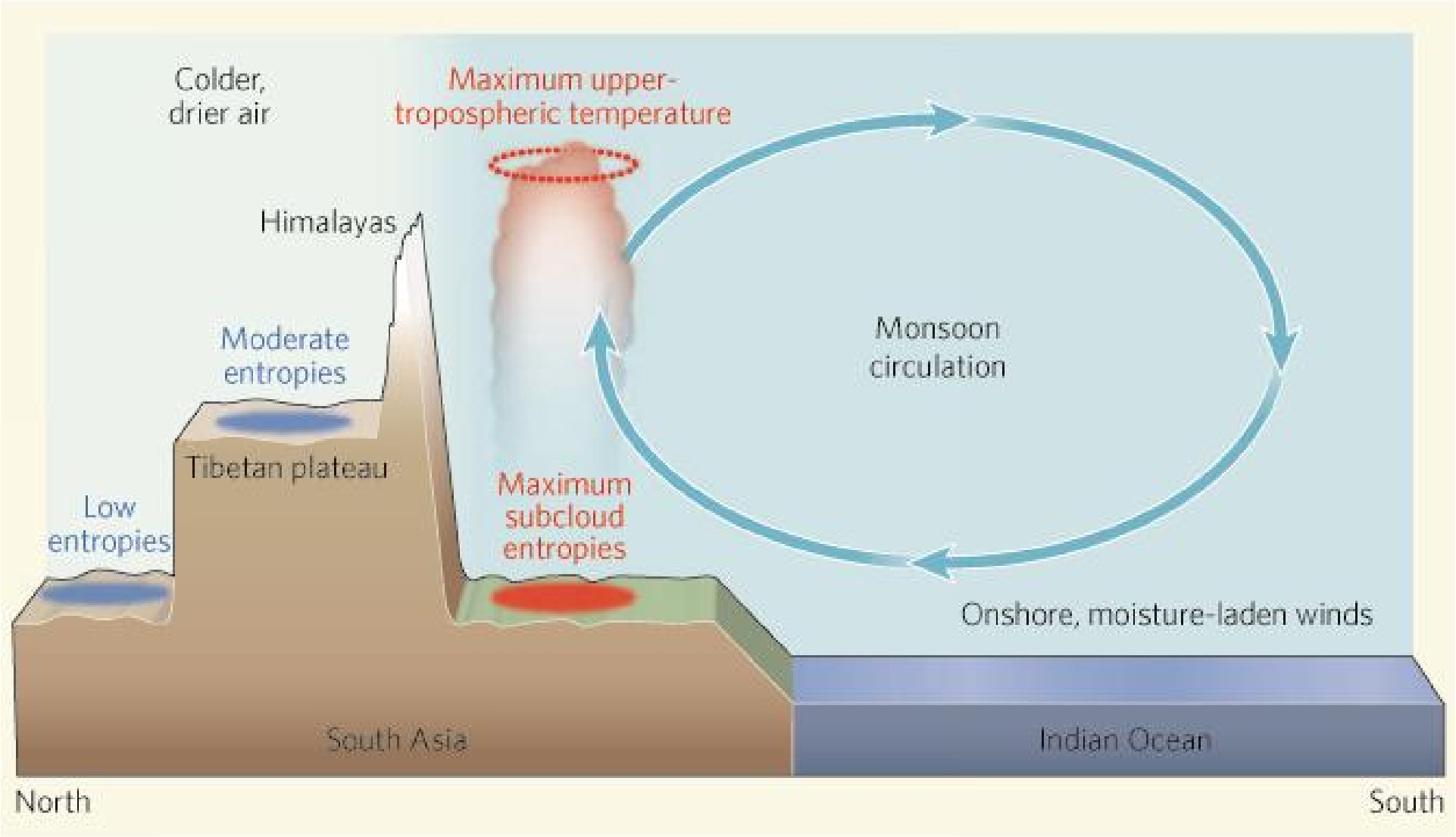
In essence, location of the main centres of precipitation during the Indian Summer Monsoon are determined by topography.

What is the role of Himalayan mountains (~8 km high) and Tibetan Plateau (~4.5 km high, 2.5 million sq. km area)?

This question was answered by Boos and Kuang (*Nature*, 14 January 2010):

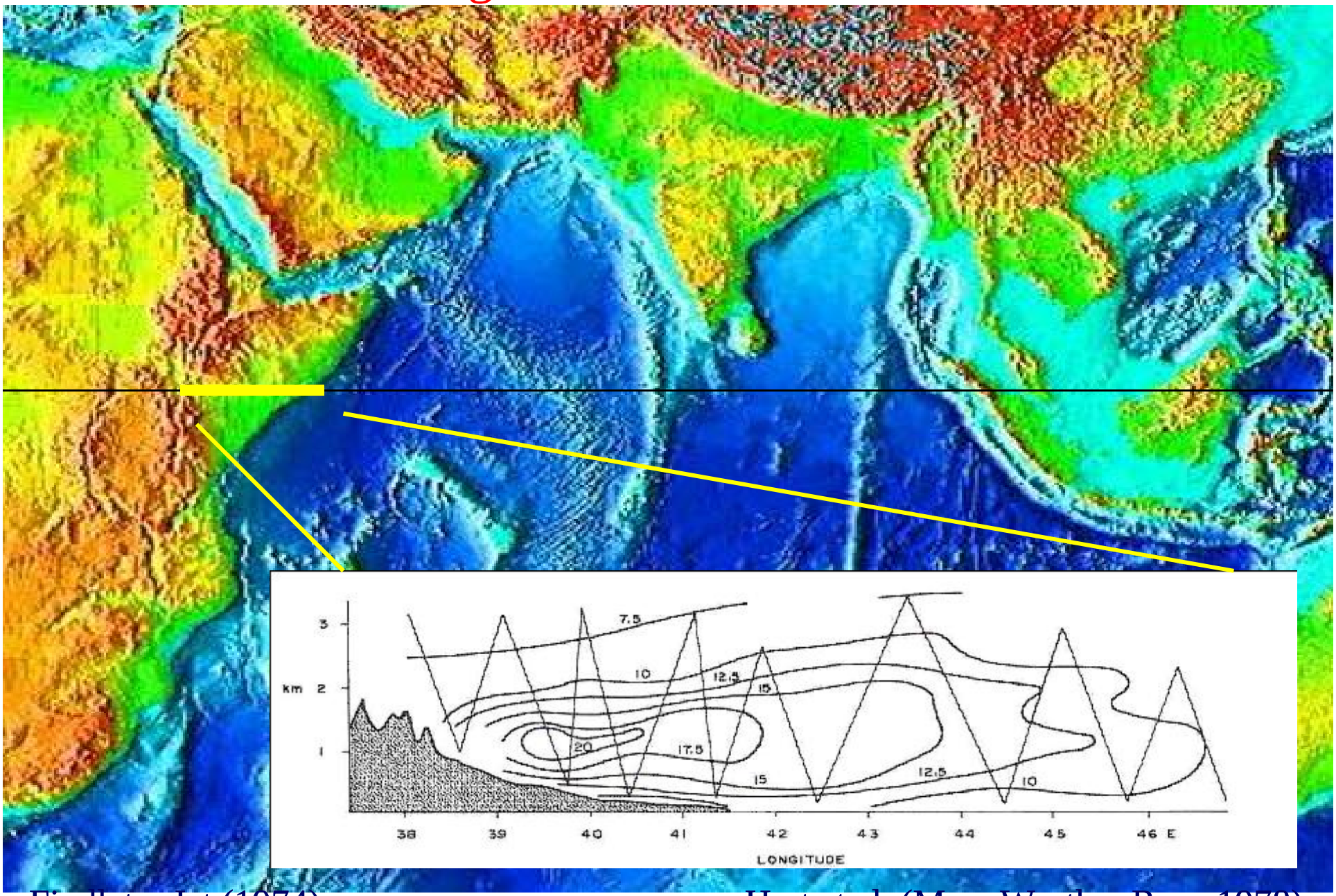
The Himalayan mountains serve as a wall that restricts movement of moisture in meridional direction.

Impact of heat released by Tibetan Plateau (in a fashion similar to that envisioned by Halley) is not significant.



Mark Cane, News & Views, Nature, 14 January 2010

What causes the strong flow in the western Arabian Sea?



Findlater Jet (1974)

Hart et al. (Mon. Weather Rev., 1978)

David Anderson (Mon. Weather Rev., 1976):

Conservation of potential vorticity forces the south-to-north cross-equatorial flow to occur only in a 'frictional layer' where the conservation constraint can be broken. The East African Mountains provide the "wall" against which the frictional layer exists.

Findlater Jet in the atmosphere is the equivalent of Gulf Stream in the ocean.

Why is there a break in the precipitation belt over the western Arabian Sea?

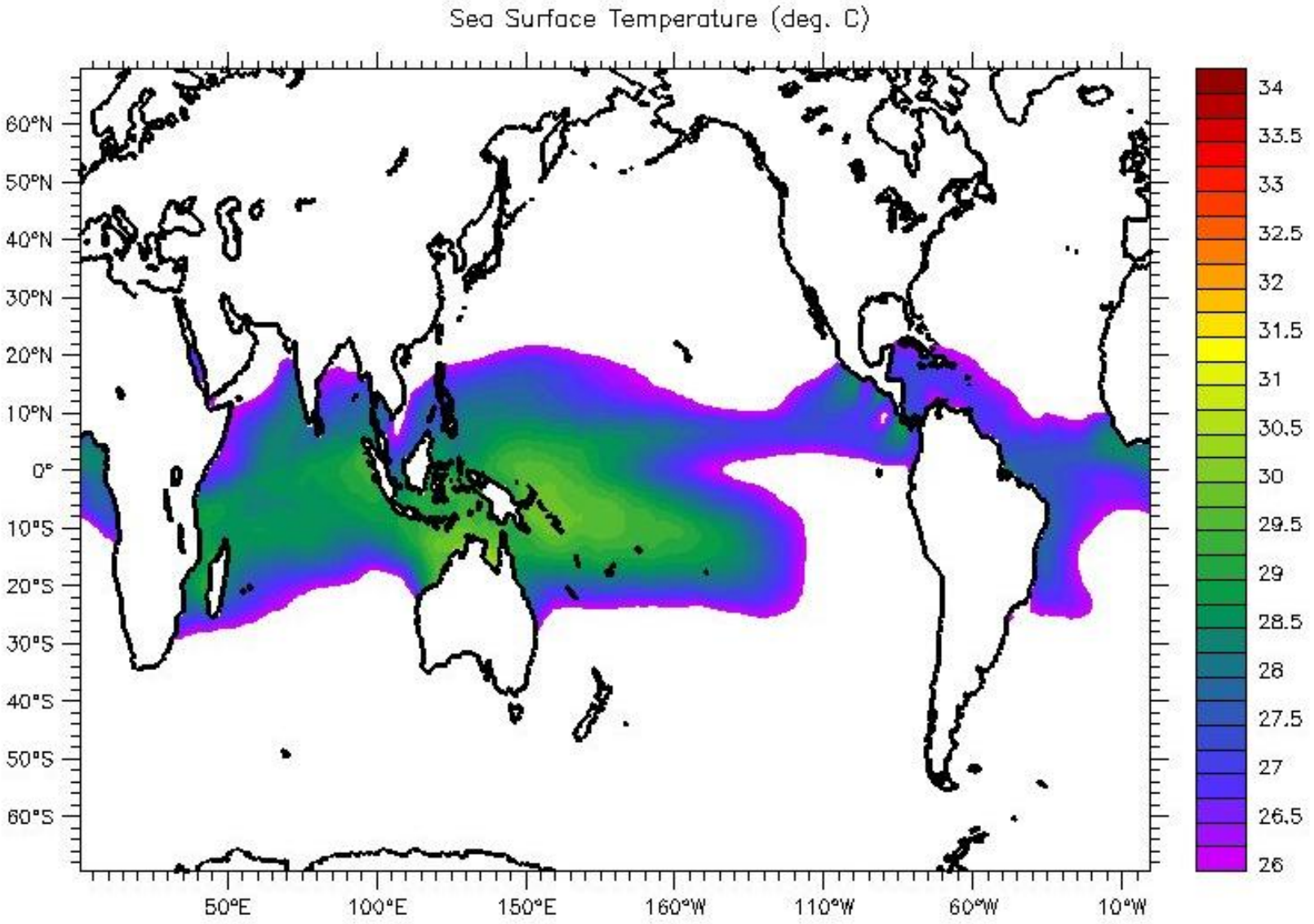
- Conditions that need to be satisfied for rainfall to occur over the North Indian Ocean:

  - ITCZ should have moved over the region, i.e. there should be large-scale convergence of air followed by uplift.

➢ Sea Surface Temperature should exceed a critical value of ~ 28 C: known earlier for tropical regions, but shown explicitly for monsoon region by Gadgil, Joseph and Joshi (*Nature*, 1984). This is a necessary condition, but not sufficient.

- How does the SST vary over the N. Indian Ocean?

JAN


Sea Surface Temperature (deg. C)
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W
34
33.5
33
32.5
32
31.5
31
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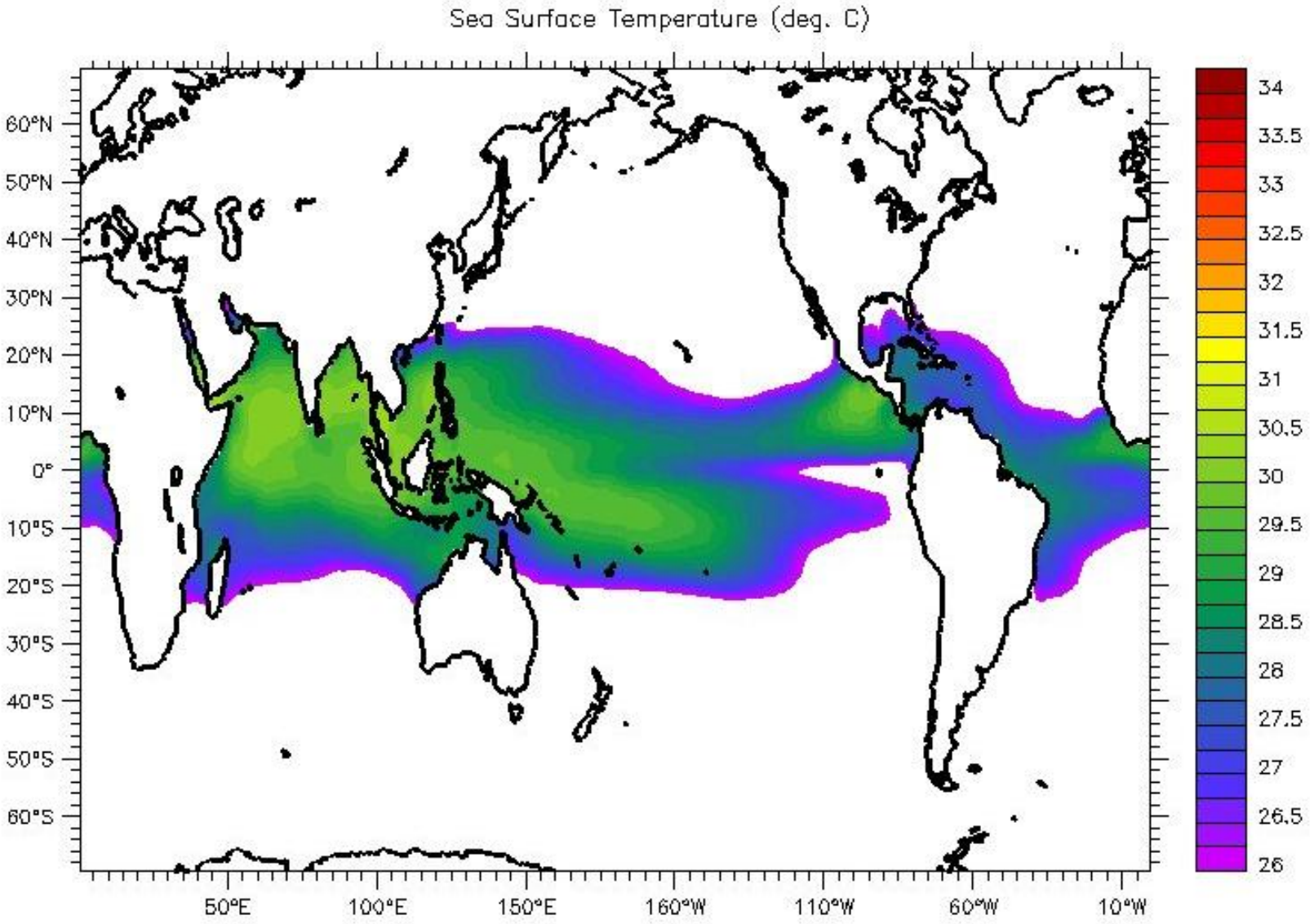
29
28.5
28
27.5
27
26.5
26

MAY


Sea Surface Temperature (deg. C)
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W
34
33.5
33
32.5
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27.5
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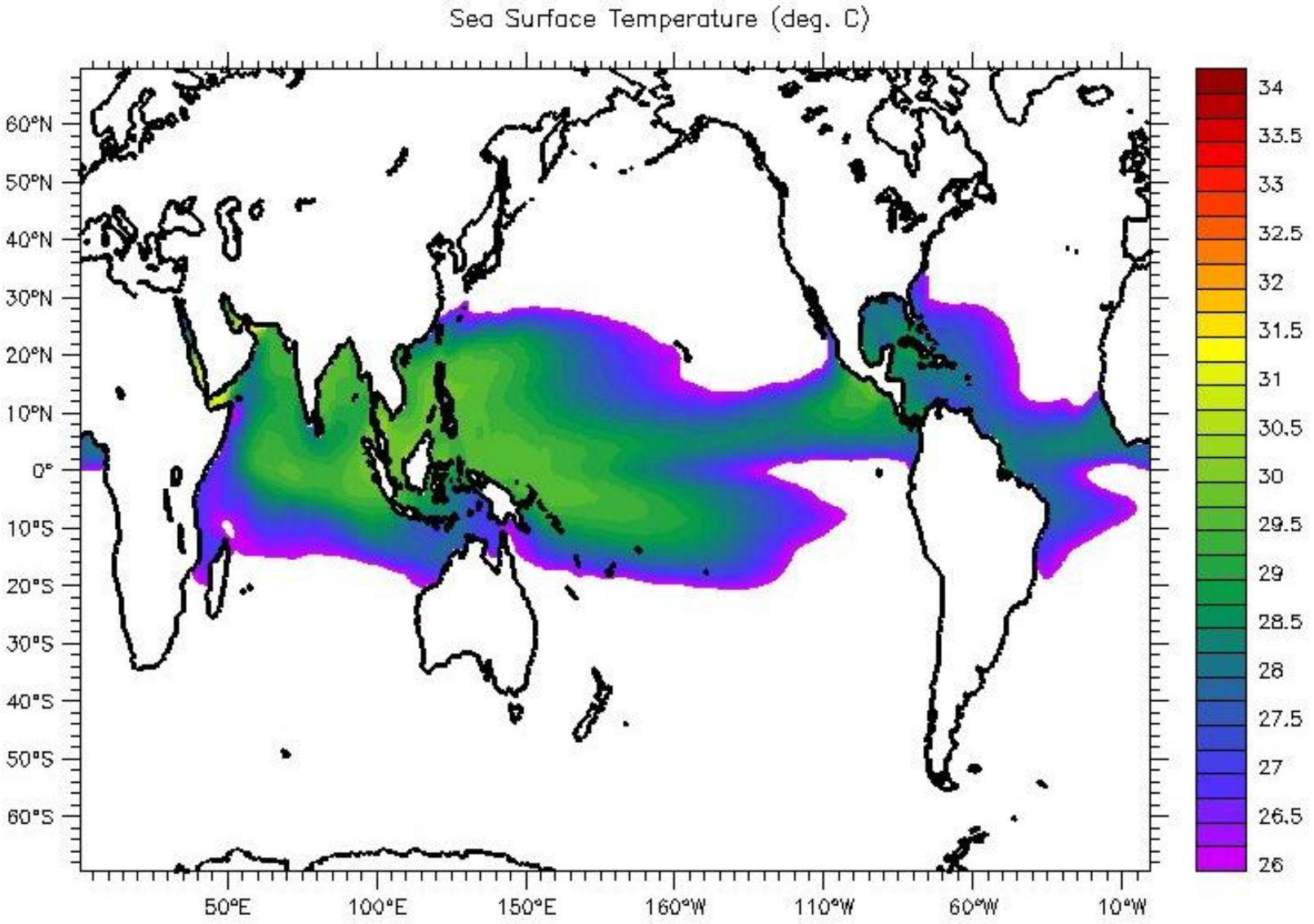
26.5
26

JUN


Sea Surface Temperature (deg. C)
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
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40°S
50°S
60°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W
34
33.5
33
32.5
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28.5
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27.5
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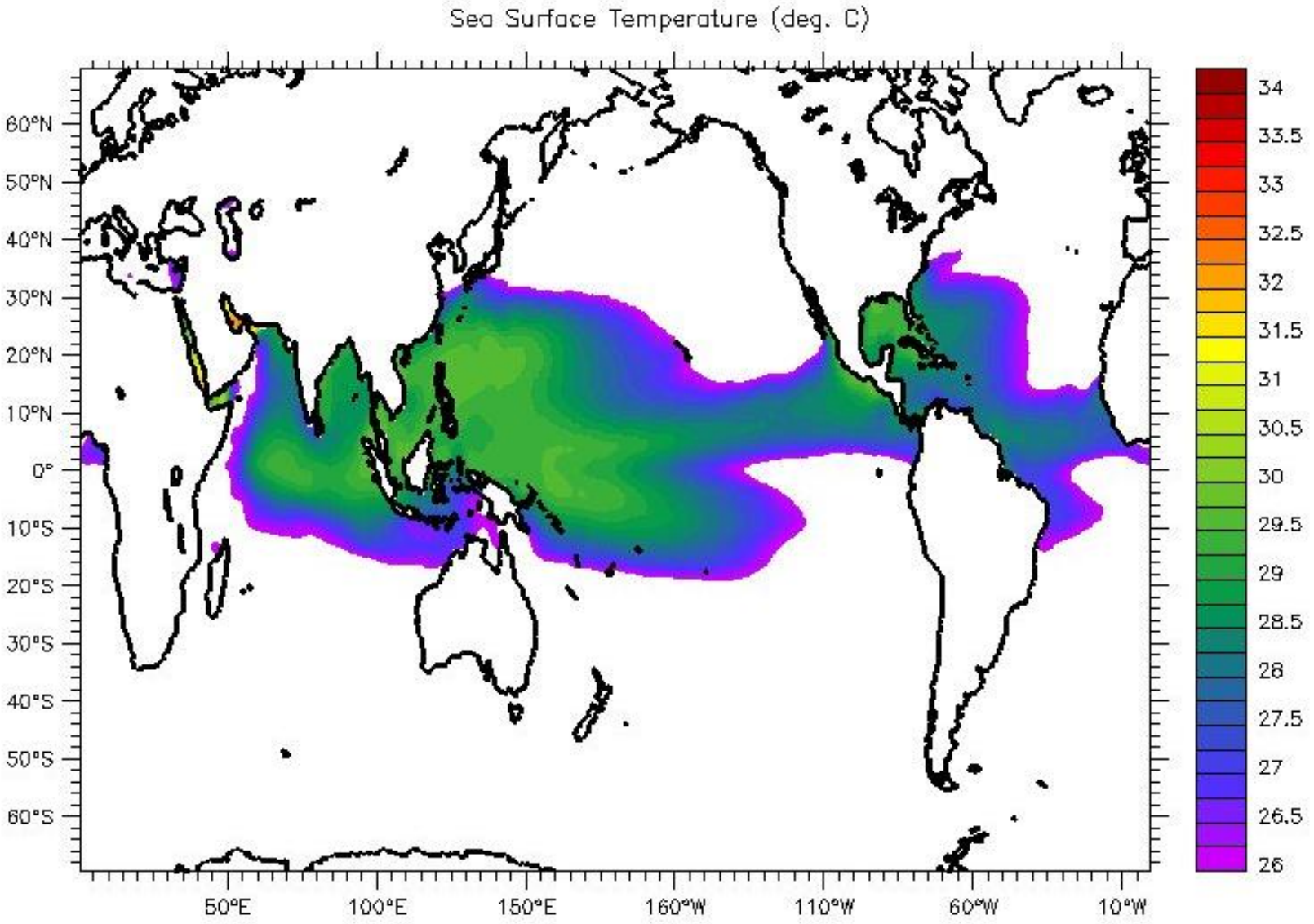
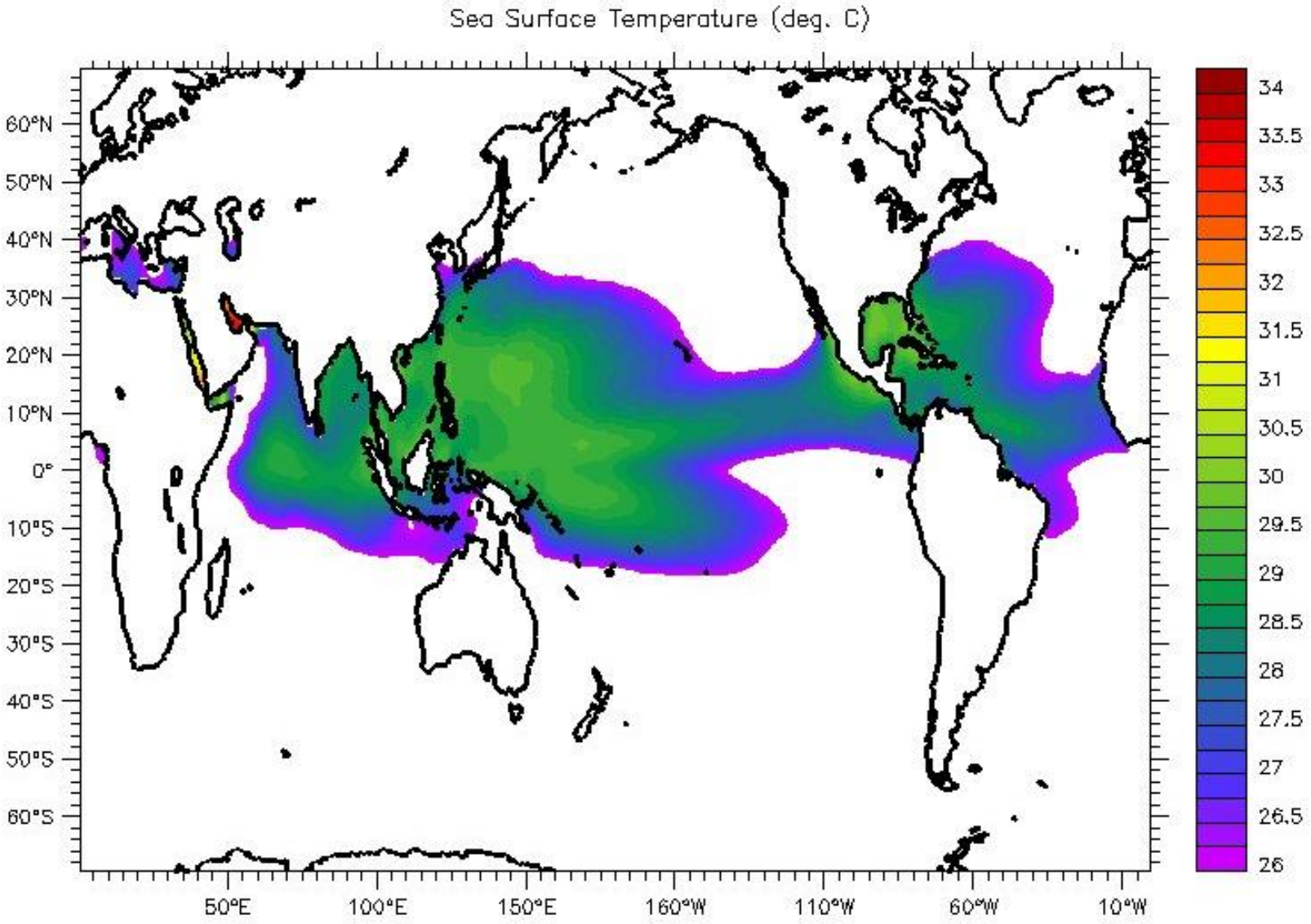
26.5
26

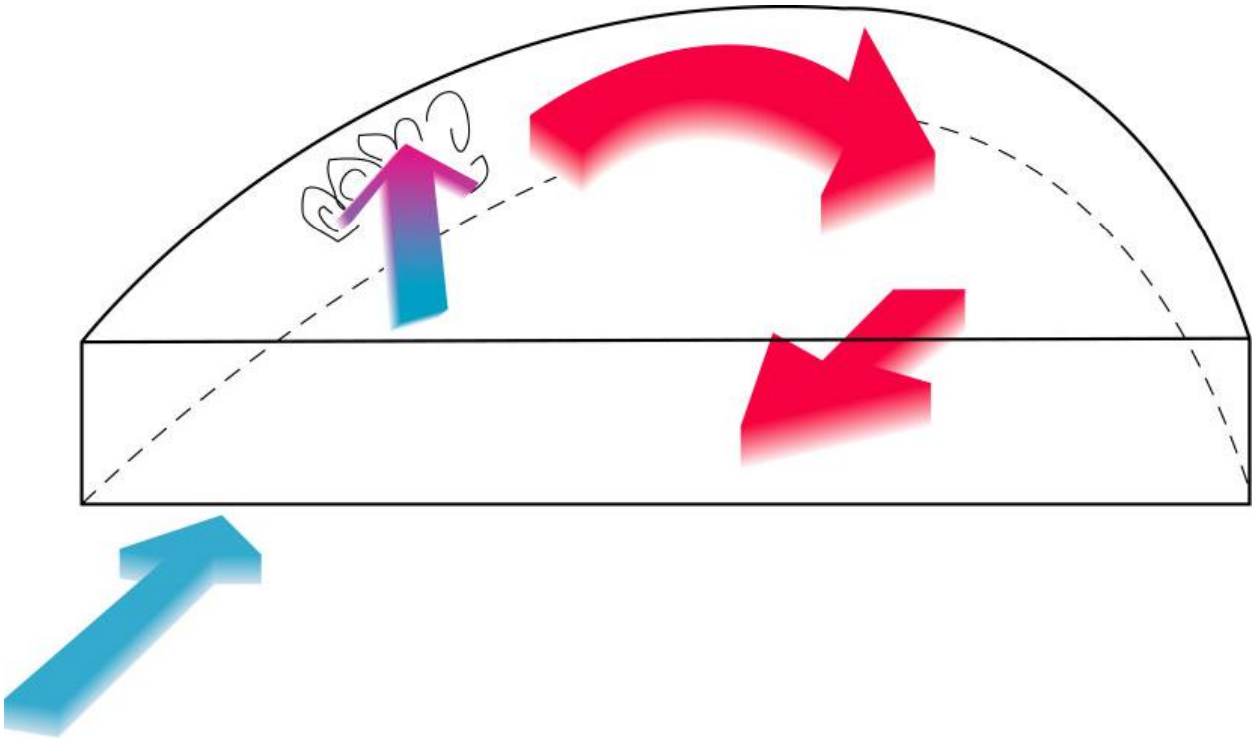
JUL


Sea Surface Temperature (deg. C)
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W
34
33.5
33
32.5
32
31.5
31
30.5
30
29.5
29
28.5
28
27.5
27
26.5
26

AUG

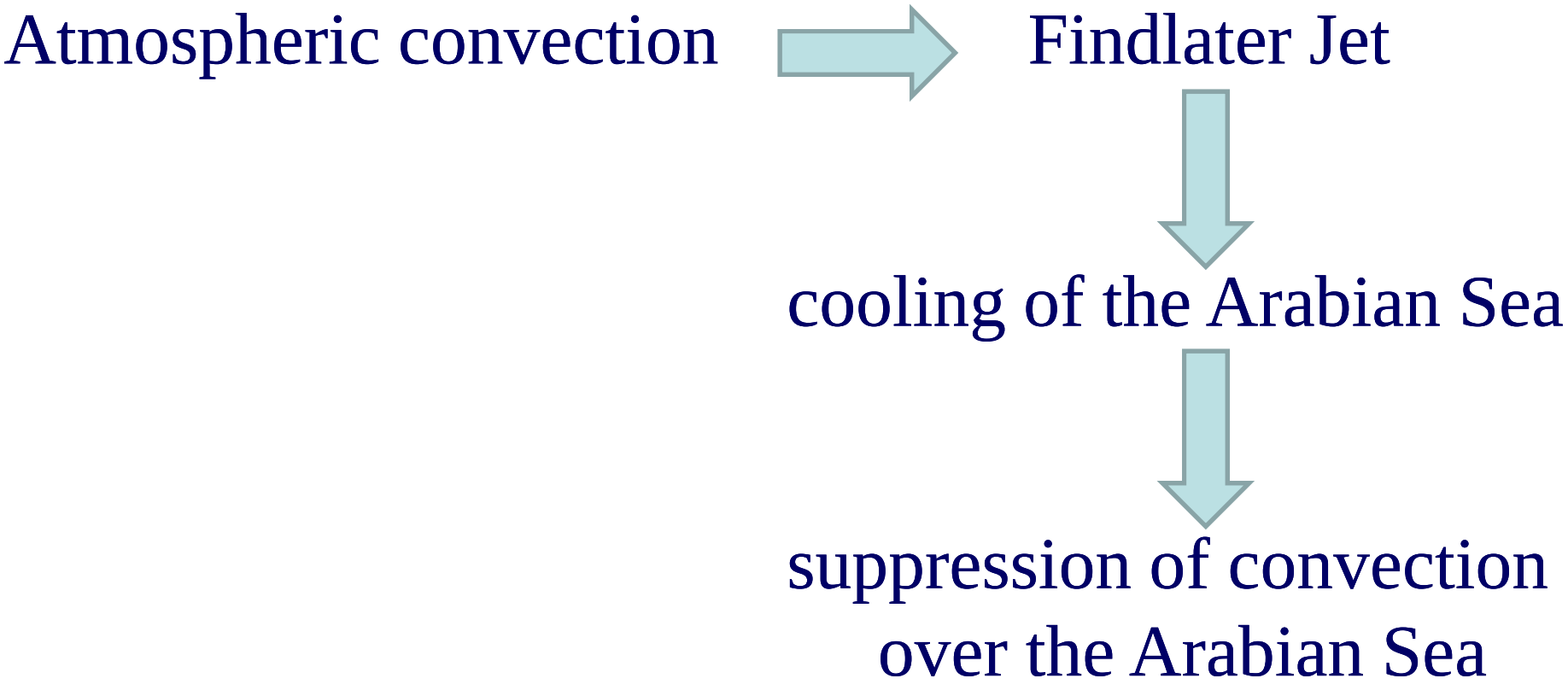

Sea Surface Temperature (deg. C)
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W
34
33.5
33
32.5
32
31.5
31
30.5
30
29.5
29
28.5
28
27.5
27
26.5
26

In the presence of Findlater Jet, cooler (deeper) northward moving waters upwell, mix with surface waters, turn eastward, then southward. The net result: cooling of the upper layer.



This phenmenon is in striking contrast to what happens over the Bay of Bengal *Shenoi, Shankar and Shetye (JGR, 1999)*

Hence there is coupling between the ocean and the atmosphere:



Over the Pacific and the Atlantic, the ITCZ is marked by

- SST maximum,
- precipitation maximum
- wind velocity minimum (justifying the name ‘doldrums’)

Their locations coincide.

During the Indian Summer Monsoon:

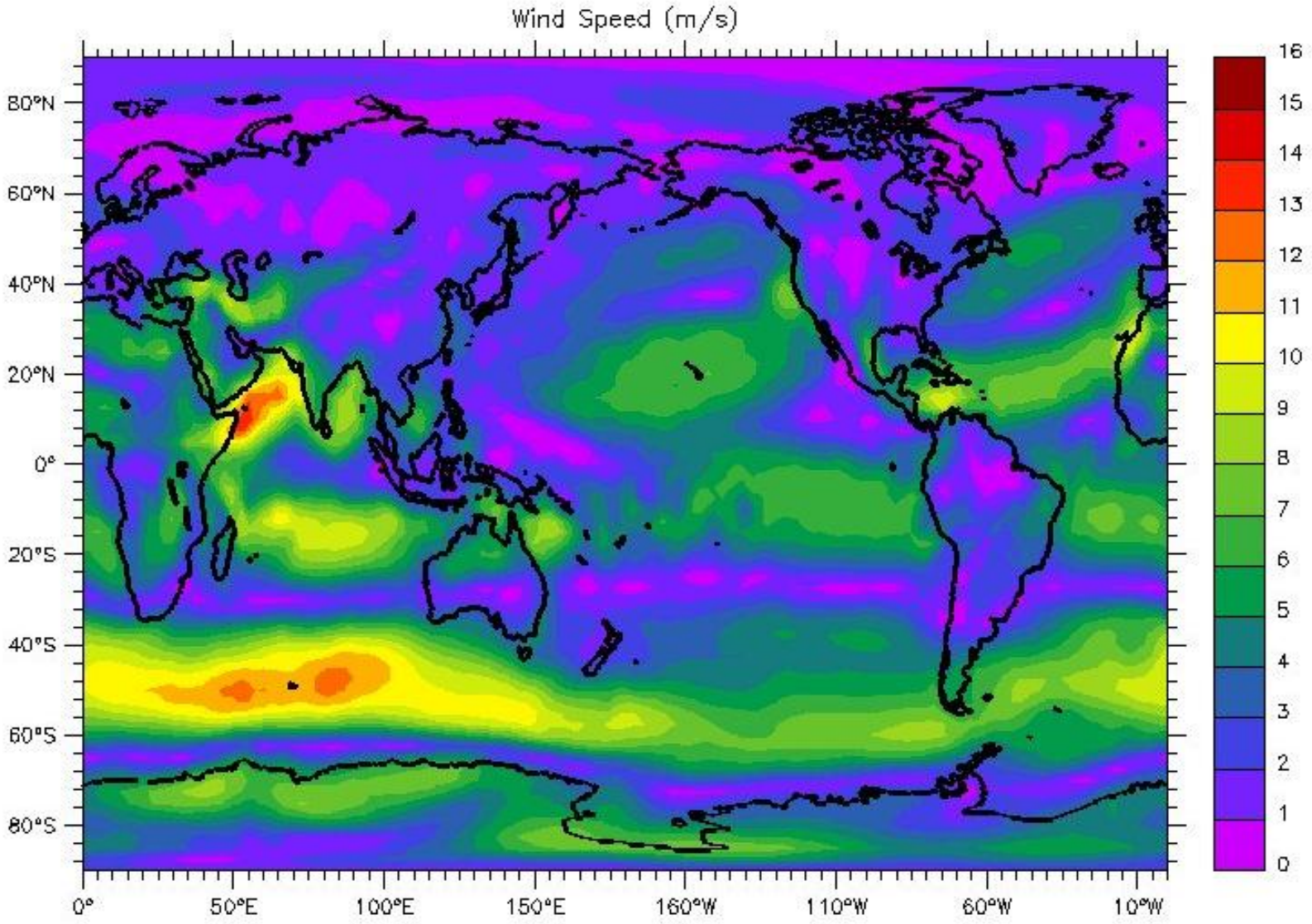
- SST maximum sits over the Bay of Bengal

- Precipitation Maxima are determined by topography and are located over NE Bay of Bengal and central eastern Arabian Sea.

- The warm Bay of Bengal supports atmospheric processes that ensure precipitation over the Indian subcontinent.

- Wind speed minimum sits over the equator

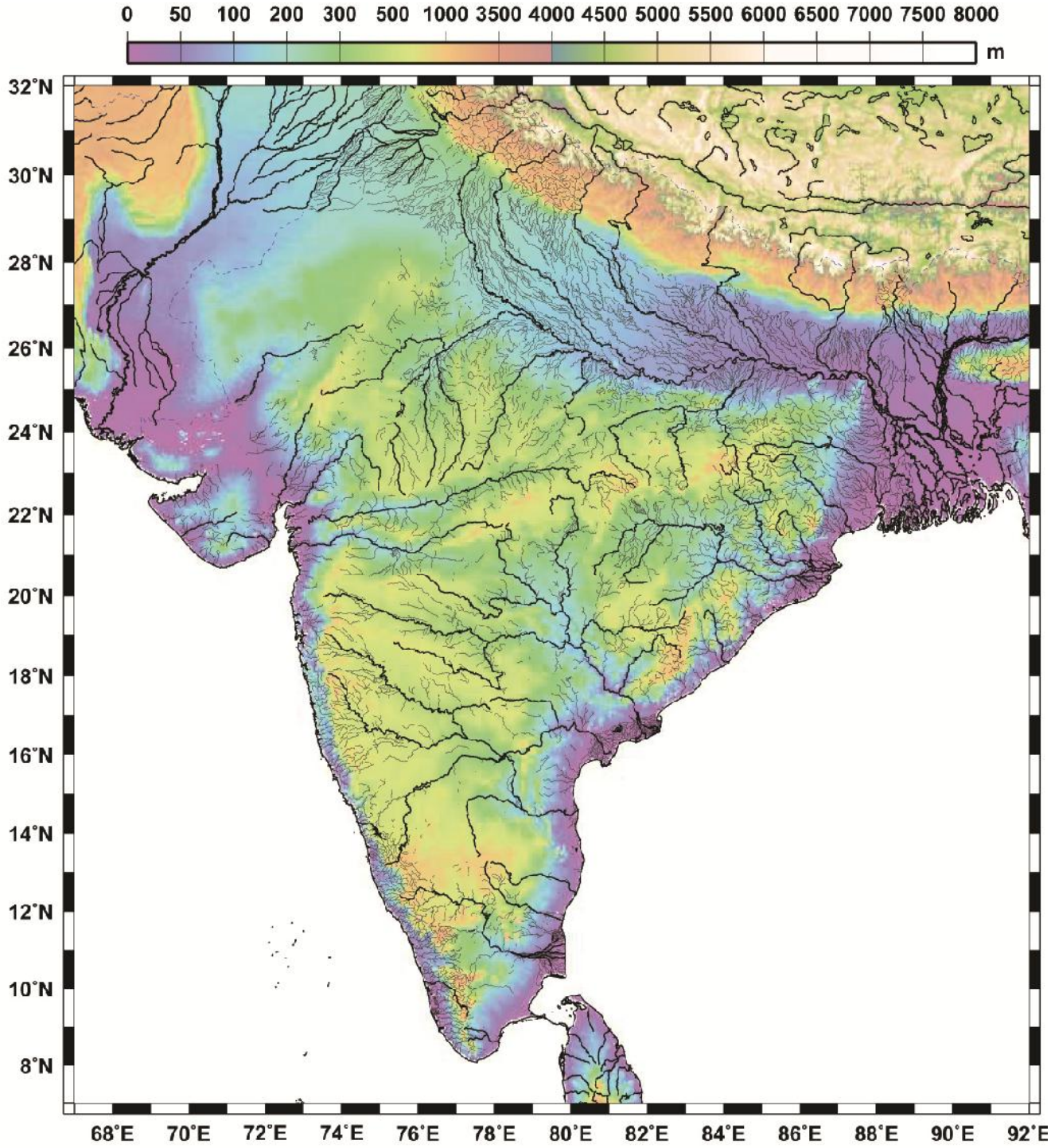
JUL


Wind Speed (m/s)
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
0°
50°E
100°E
150°E
160°W
110°W
60°W
10°W
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

While there are similarities between movement of the ITCZ over the N. Indian Ocean and other oceans, there are differences too.

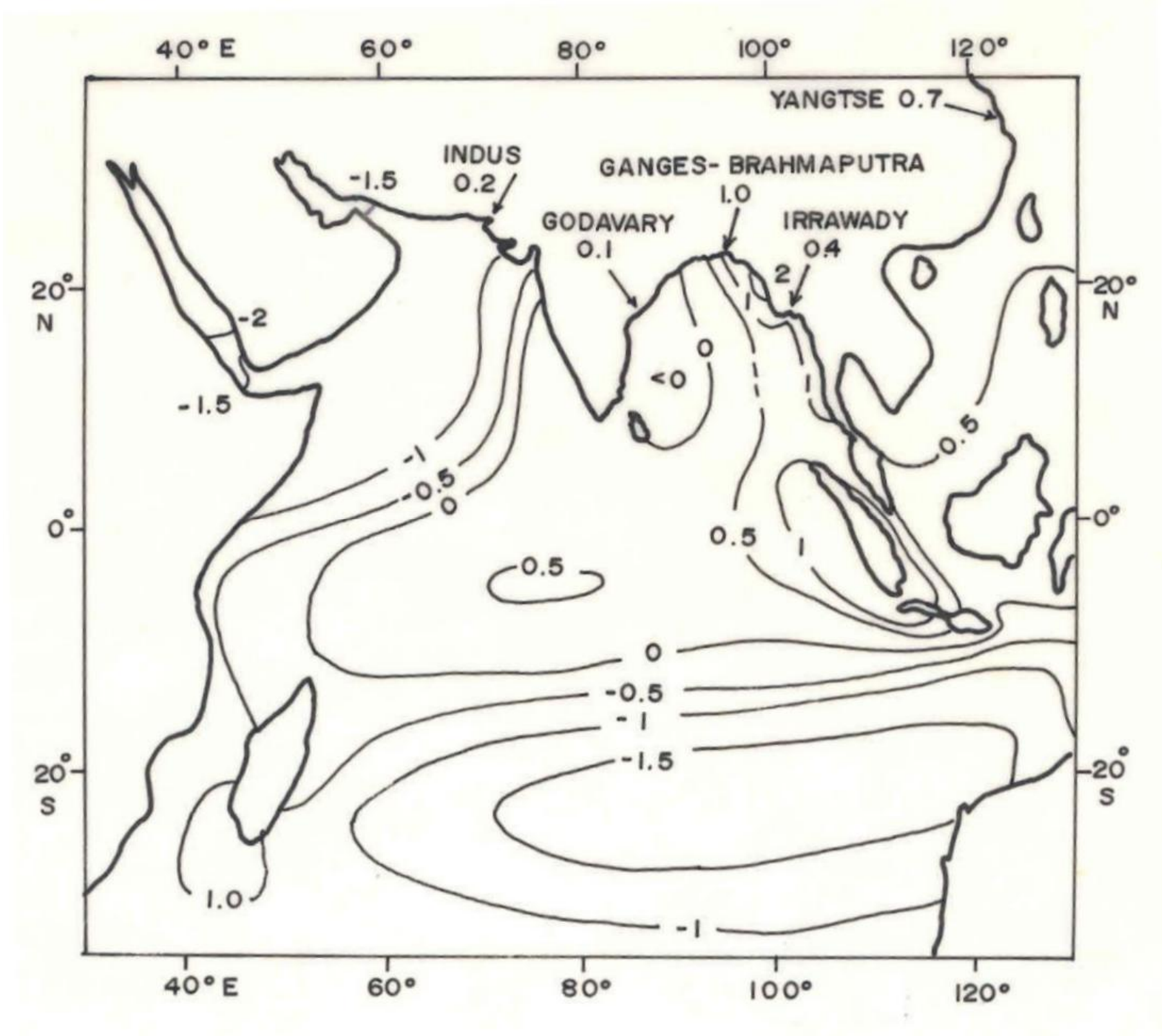
Have seen why precipitation maxima sit over the west coast and over the Northeast

Are there phenomena that are important to bring rain to other locations? Does the ocean play a role in these?

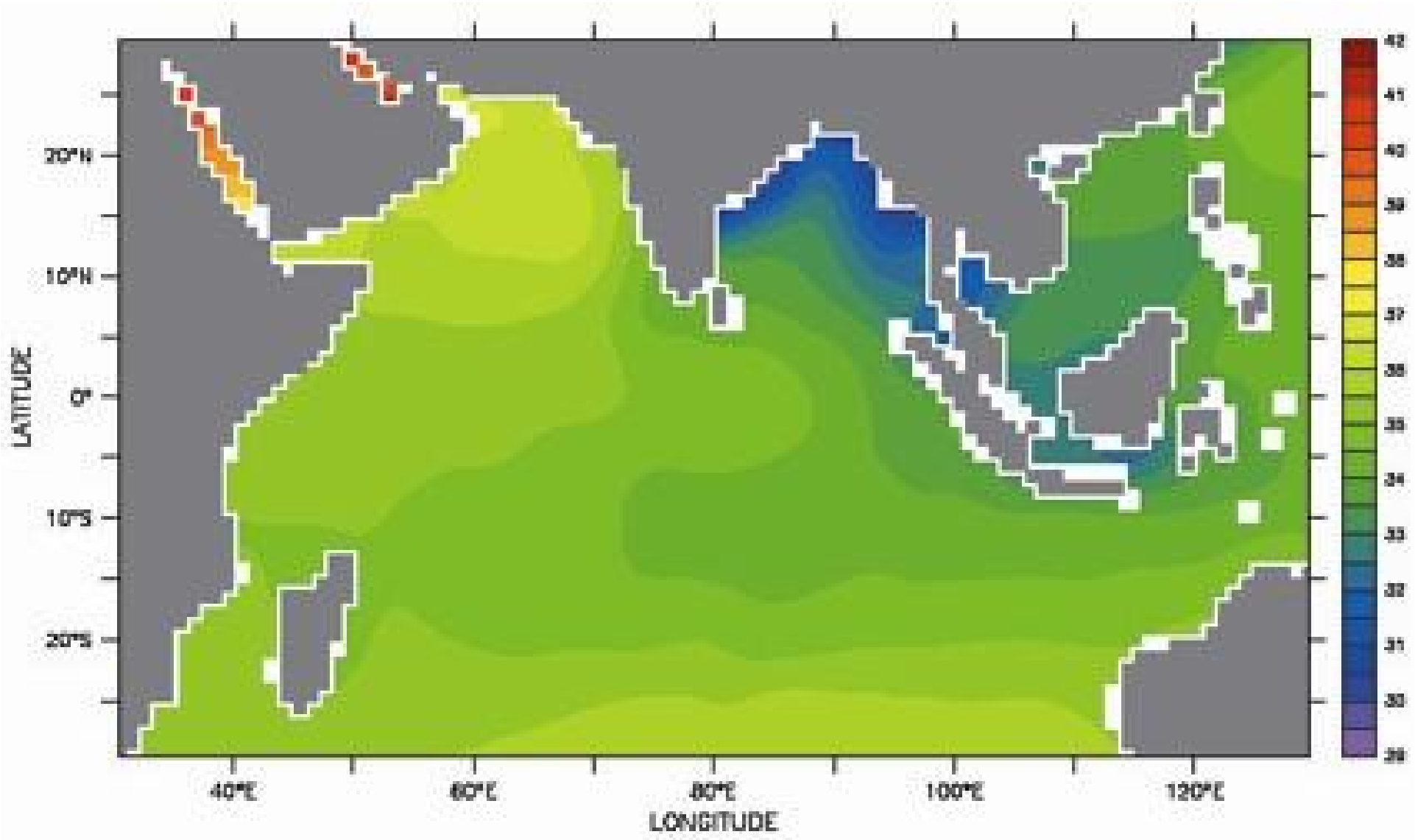


East coast: Long delta-forming rivers

West coast: short and swift rivers

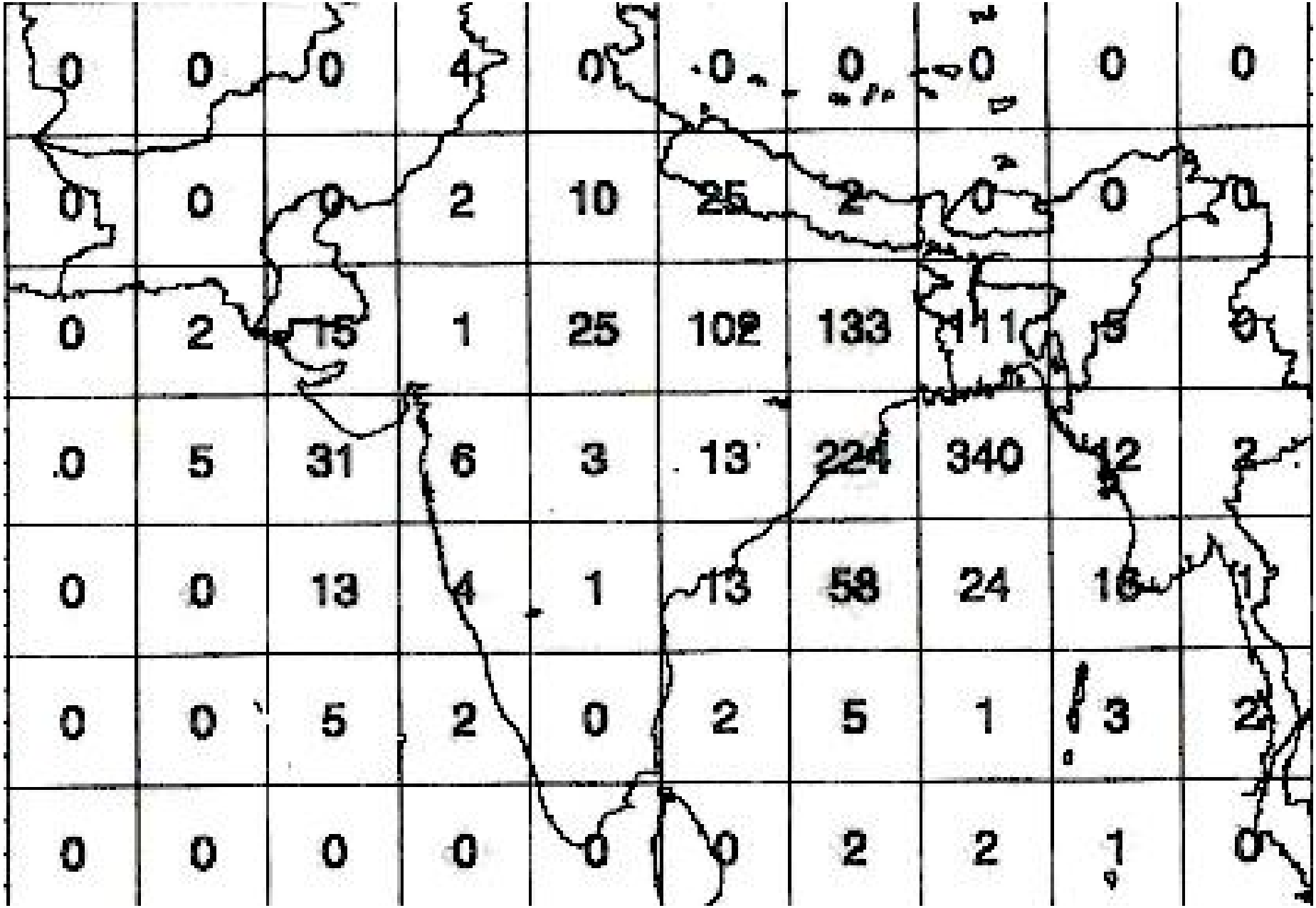


River runoff in 10^{12} m^3/year; (P-E) in m/year.

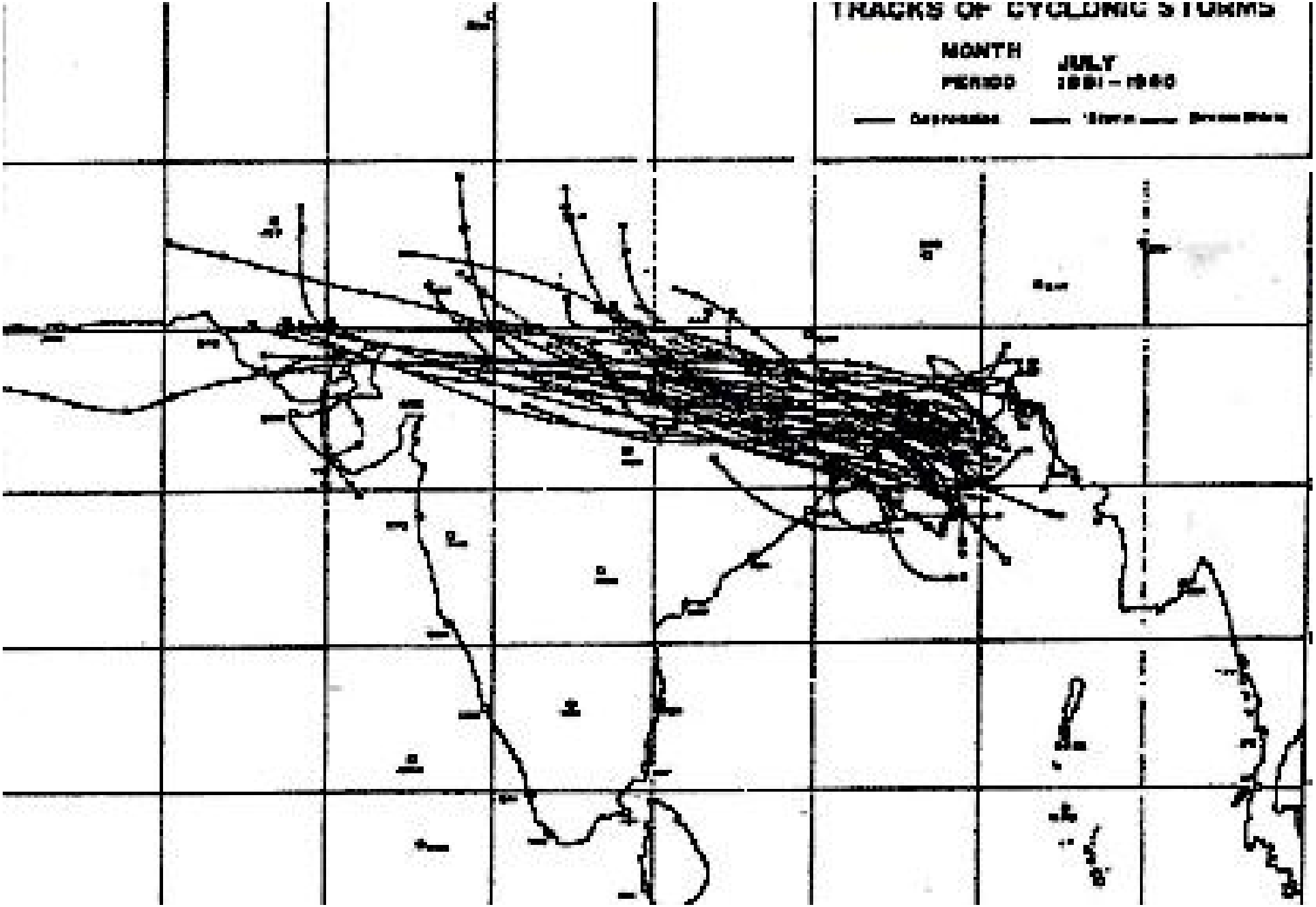

20°N
10°N
0°
10°S
20°S
LATITUDE
40°E
60°E
80°E
100°E
120°E
LONGITUDE

Weak winds over the Bay of Bengal and a well stratified surface layer due to freshwater help in keeping the bay significantly warmer than the Arabian Sea.

A warm sea can provide energy to the atmosphere to generate low pressure systems (LPS) or depressions.



Number of LPS formed in June-September over 4 x 4 deg. Sq. during 1888-1983; Mooley and Shukla (1989)



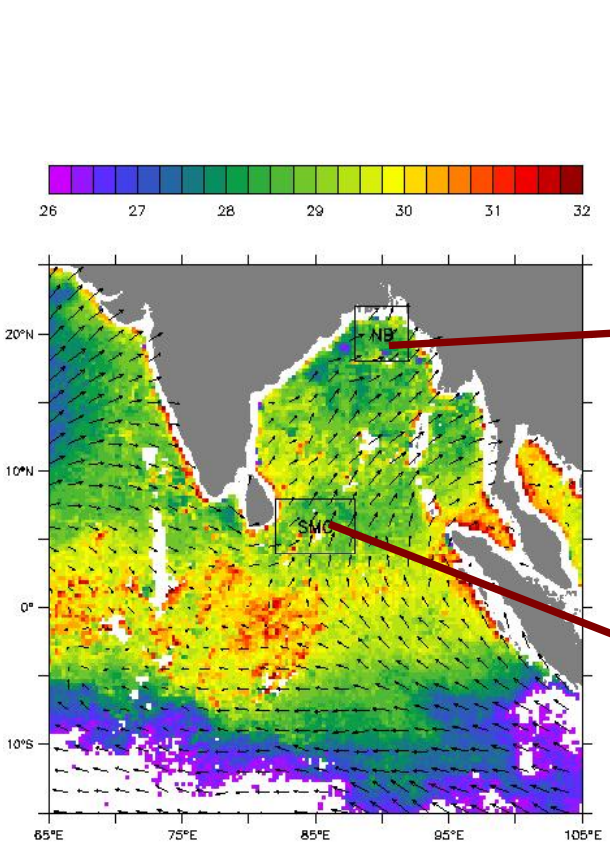
India Meteorology Department

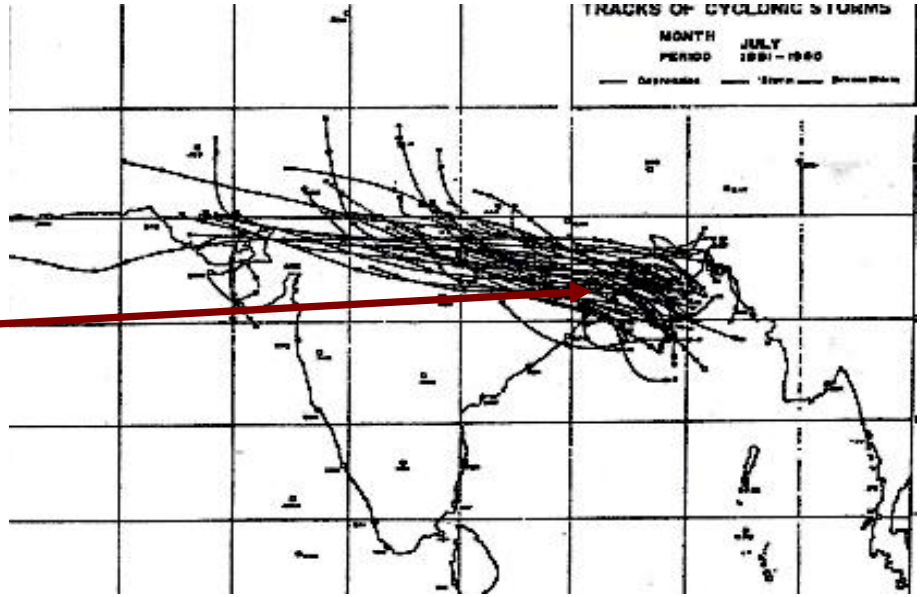
- By staying warm during the monsoon season (i.e. when the ITCZ is over the region) the Bay of Bengal makes it possible for a large area of the peninsular India to receive rainfall.

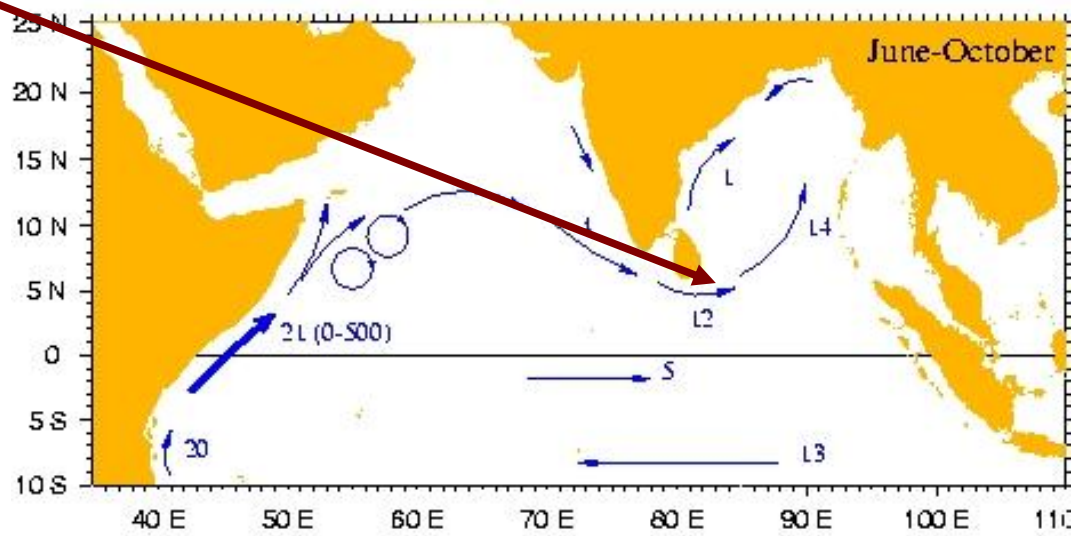
- Arabian Sea is much too cool to play such a role.

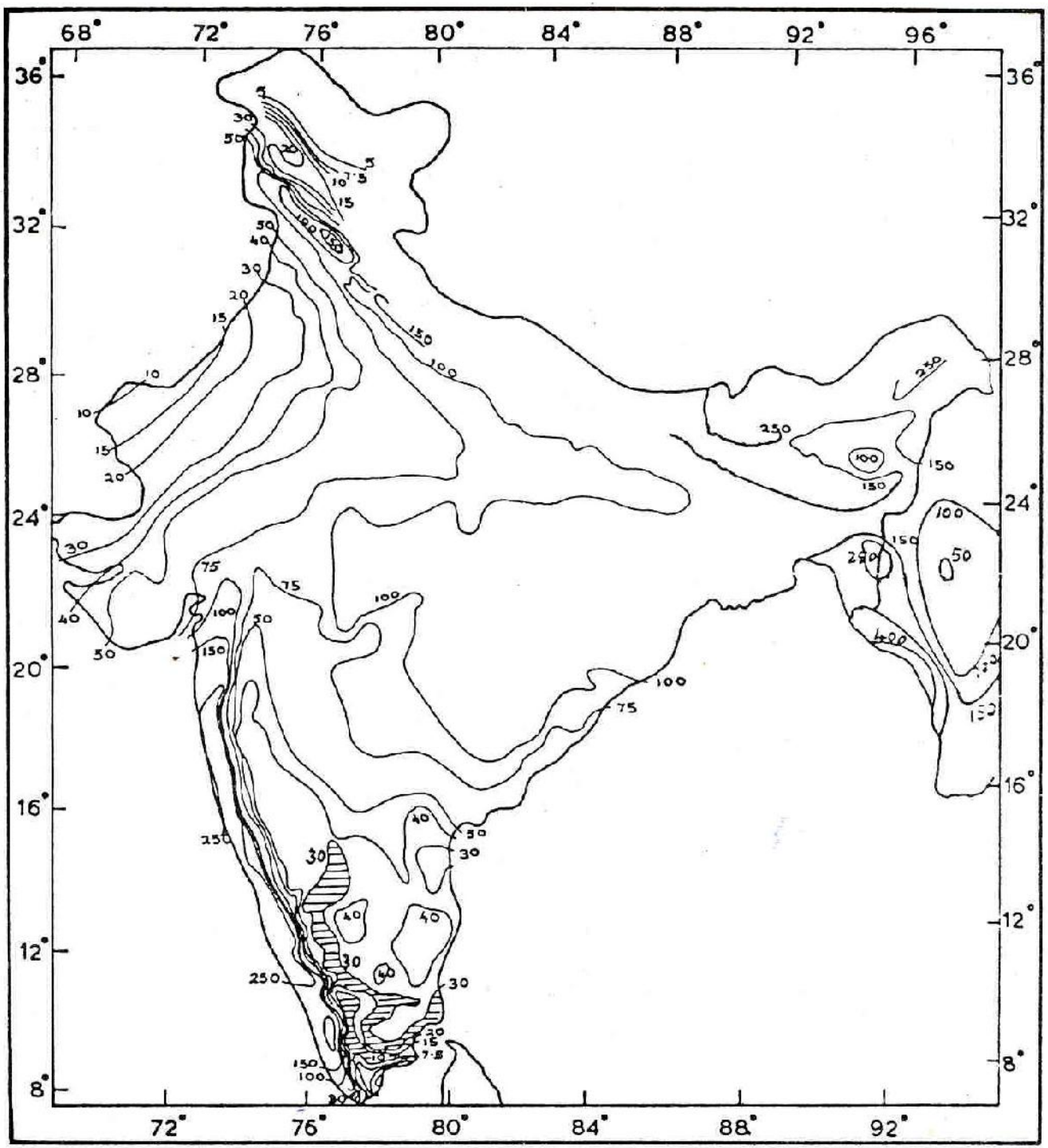
- Aden and Oman, which sit on the west of the Arabian Sea receive very little precipitation in comparison to India.

- If SST over the bay is so important could use it to predict precipitation?


26
27
28
29
30
31
32
20°N
10°N
0°
10°S
NB
SMC
65°E
75°E
85°E
95°E
105°E


TRACKS OF CYCLONIC STORMS
MONTH
JULY
PERIOD


June-October
25 N
20 N
15 N
10 N
5 N
0
5 S
10 S
40 E
50 E
60 E
70 E
80 E
90 E
100 E
L
L4
L2
L3
S
20


68°
72°
76°
80°
84°
88°
92°
96°
36°
32°
28°
24°
20°
16°
12°
8°

- A rainfall event over the central bay can be expected to occur soon after the northern bay SST exceeds 29°C.

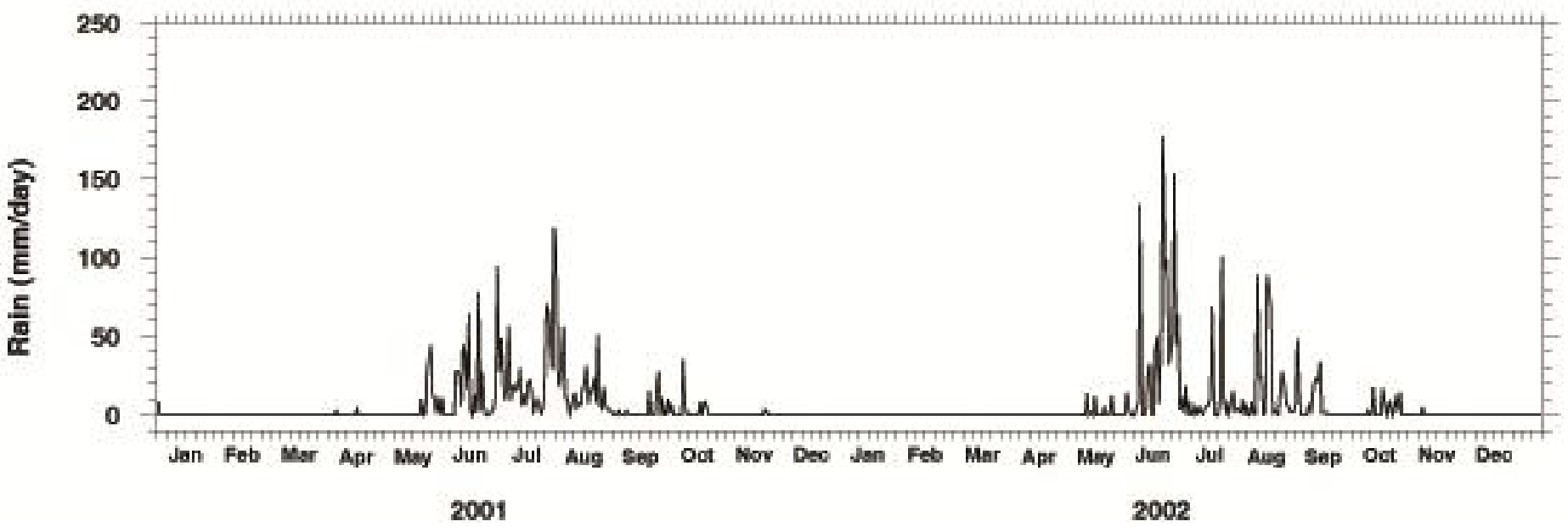
- The rainfall event is extremely likely to occur within a week of the SST difference between the northern and southern bay exceeding 0.75°C (78% chance of this during May–September).

- The convection over the bay is a precursor to convection over India.

Shankar, Shetye, and Joseph (2007)

- All this is useful to understand occurrence of the monsoon to first-order.

- It does not help to predict the monsoon behaviour (temporal and spatial variability) during a season.



- Country's farmers need to know this variability.

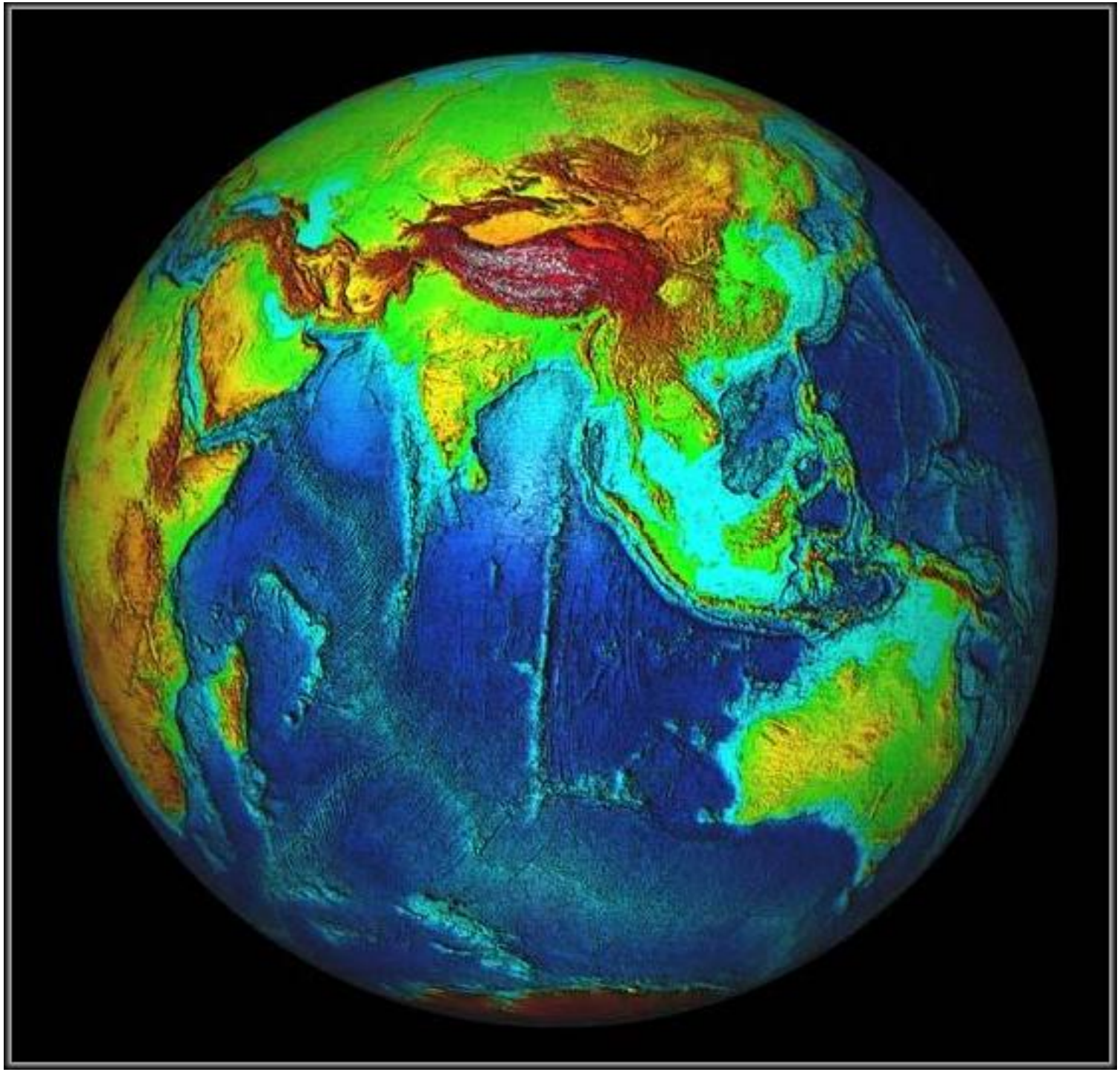
Summary

The winds and associated precipitation over the Indian subcontinent are a consequence of local modification of the ITCZ that girdles the globe. The main players in the modification:

- Topography (East African Mountains, Sahyadris/Western Ghats, Arakan Range, and Himalayas)

- Impact of the ocean (cooling in the Arabian Sea, warming of the Bay of Bengal, setting up of SST gradient over the bay.....)

Thank You



The Indian Summer Monsoon

Agriculture accounts for about 52% of employment in India.

Only about 50% of the land is irrigated

A good monsoon results in a robust growth for the economy as a whole, while a poor monsoon leads to a sluggish growth.

Source: Wikipedia