Dynamical response of the South Asian monsoon trough to latent heating from stratiform and convective precipitation

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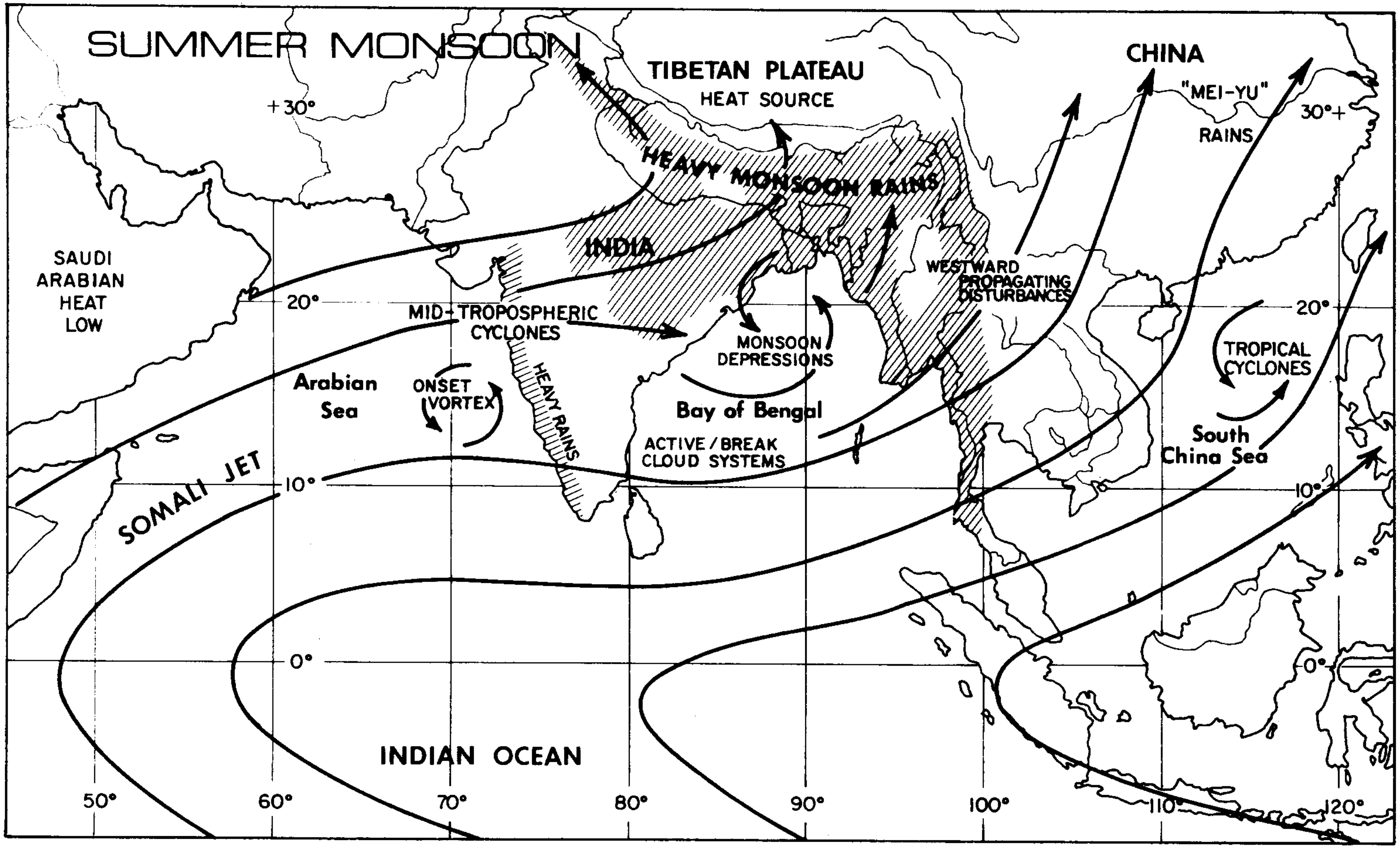
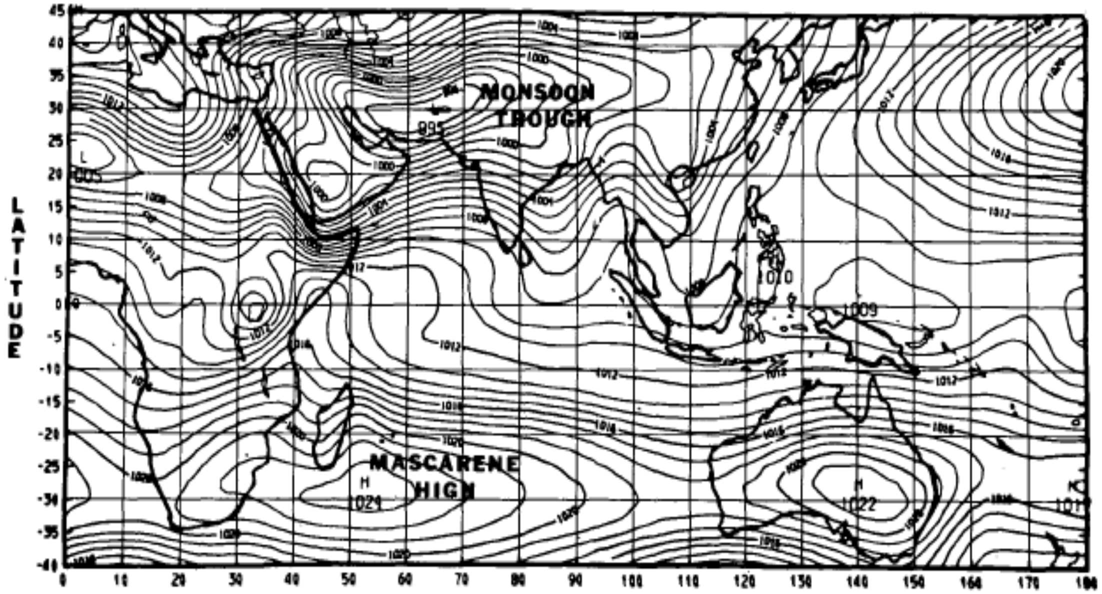


(Johnson, R. H., and R. A. Houze, Jr., 1987)

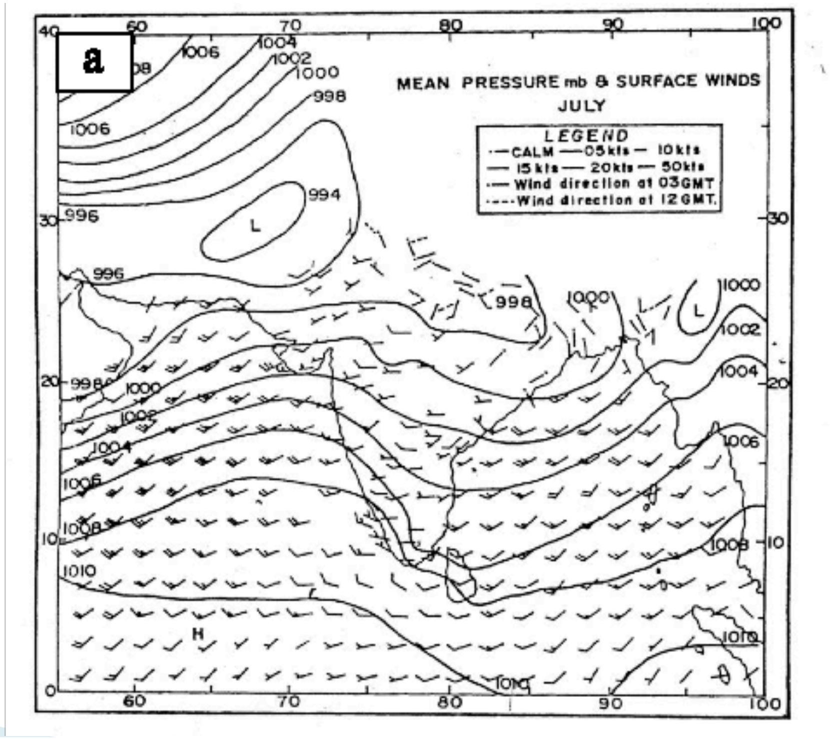
Primary synoptic and smaller-scale circulation features that affect cloudiness and precipitation in summer monsoon region. Locations of June to September rainfall exceeding 100 cm over the land west of 100^{o}E associated with the southwest monsoon are indicated (from Rao, 1981). Those over water areas and east of 100^{o}E are omitted.



Mean sea level pressure for July (Courtesy of Henry Van de Boogard) – Adapted from Krishnamurti and Bhalme (1976)

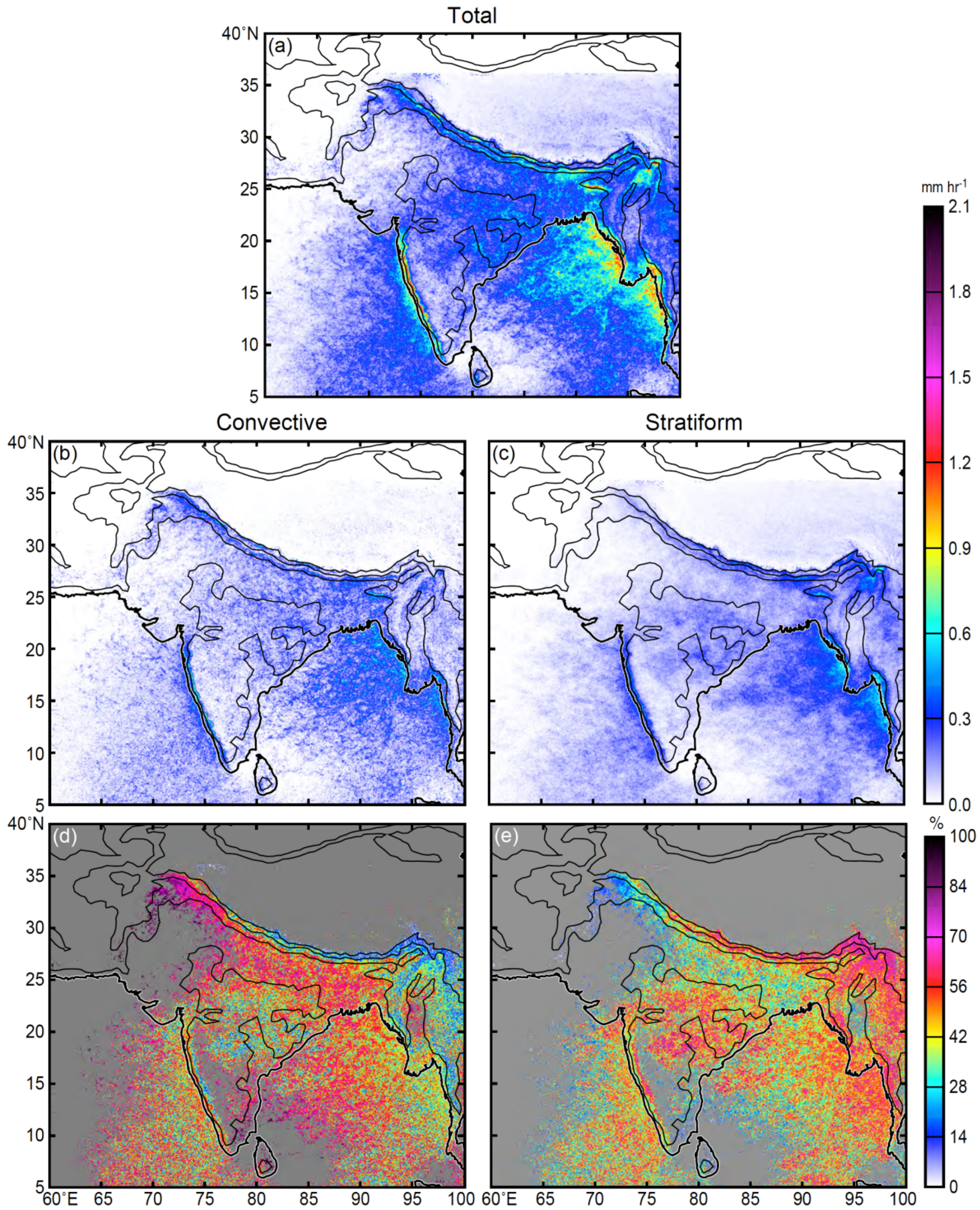
South Asian Monsoon Trough

July mean SLP (hPa) and surface wind (knots) (Sikka and Narasimha 1995)



Climatology of TRMM PR Rainfall

Convective and stratiform contributions

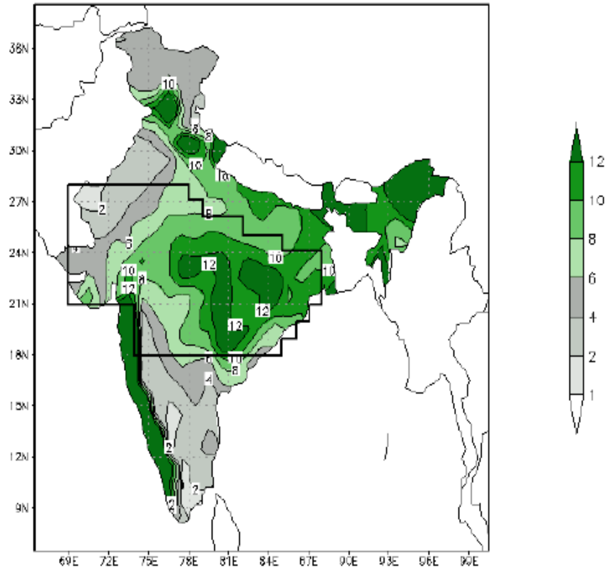


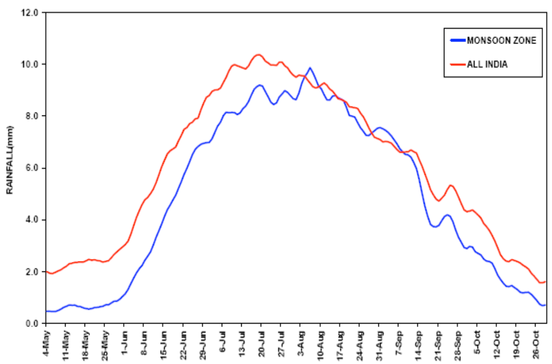
Courtesy: R. Houze

Active and Break Monsoon Variability

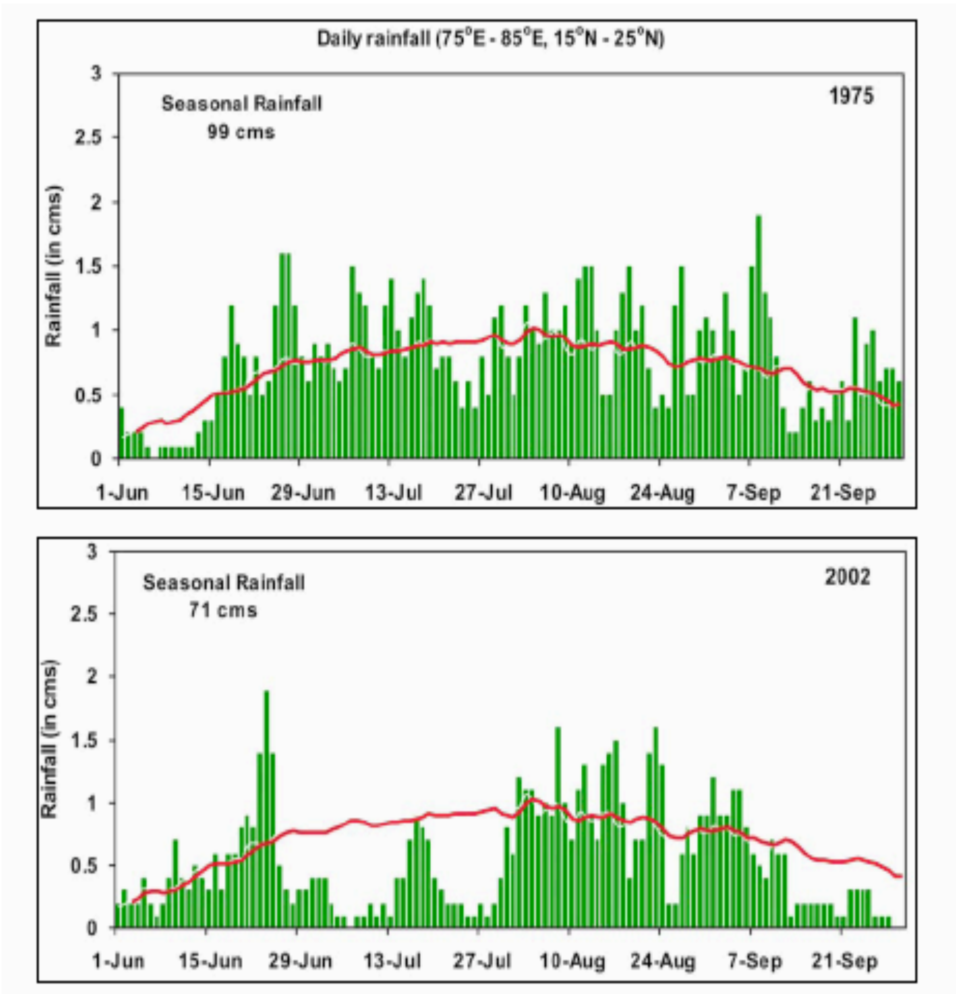
Monsoon core zone considered
to identify active events

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





Daily rainfall climatology over Monsoon Zone (blue) and All India (red) based on data for the period (1951 – 2004).



Variation of the daily rainfall over central India during the June to September months

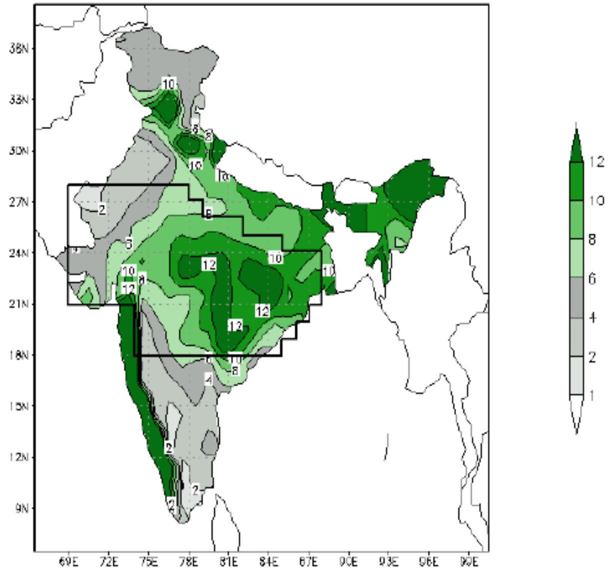
(a) 1975 (Excess monsoon year)

(b) 2002 (Drought monsoon year)

Rajeevan, Gadgil and Bhate (2008): NCC Res Report No.3. India Met. Dept. Pune

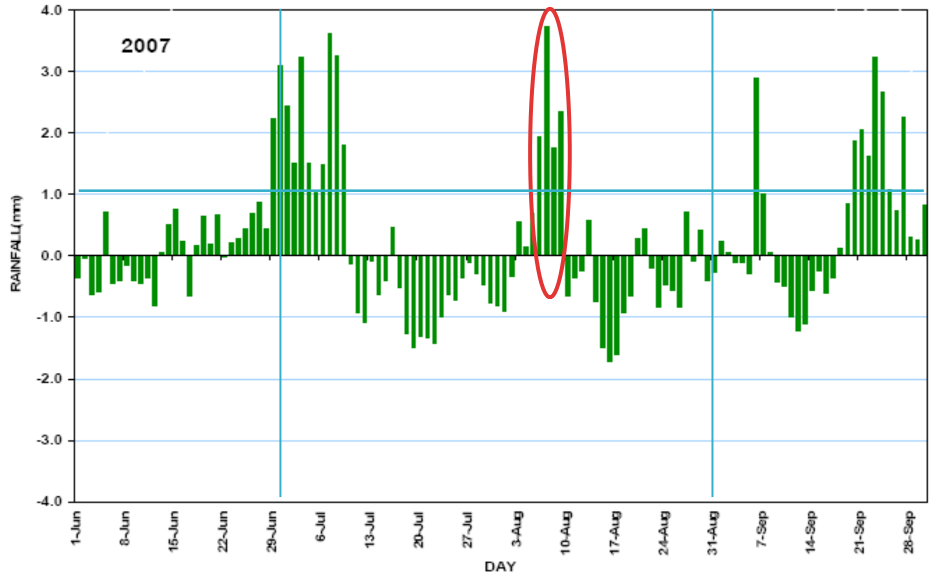
Monsoon core zone considered to identify active events

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



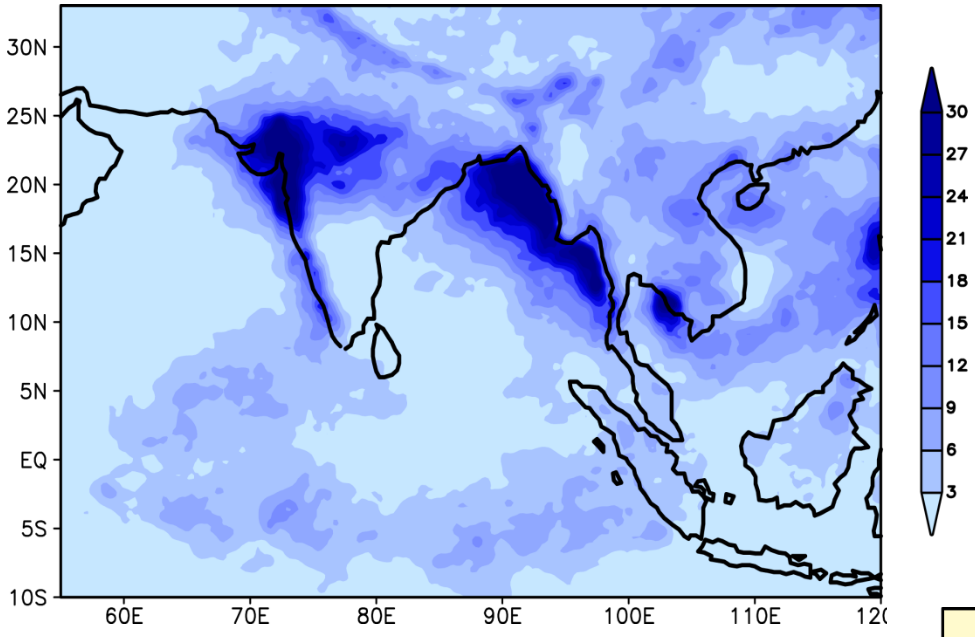
Active Monsoon Variability

Daily standardised rainfall time series averaged over the monsoon zone



Year	Active monsoon spells
1998	3 - 6 July
2000	12 - 15 July; 17 - 20 July
2001	9 - 12 July
2003	26 - 28 July
2004	30 July - 1 August
2005	1 - 4 July; 27 July - 1 August
2006	3 - 6 July; 28 July - 2 August; 5 - 7 August; 13 - 22 August
2007	1 - 4 July; 6 - 9 July; 6 - 9 August

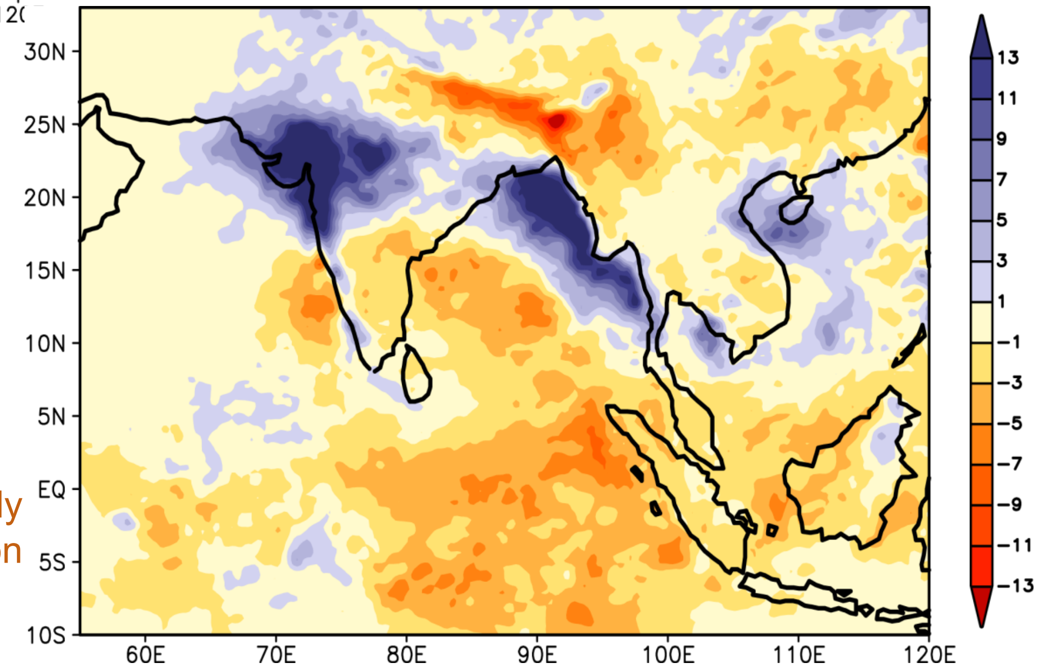
Rajeevan, Gadgil and Bhate (2008): NCC Res Report No.3. India Met. Dept. Pune



Composite map of rainfall (mm day $^{-1}$) based on active monsoon days. The data is from TRMM 3B42 daily rainfall dataset.

Active Monsoon

Large-scale organization of meso-scale convective systems MCS (3000-4000 km)



Composite map of rainfall anomaly (mm day $^{-1}$) based on active monsoon days.

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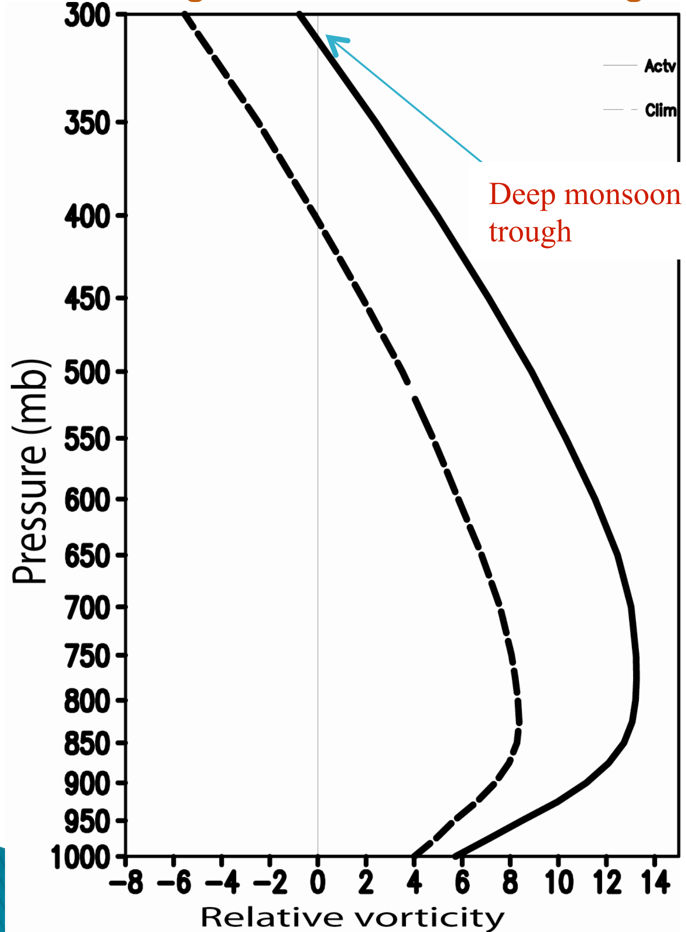
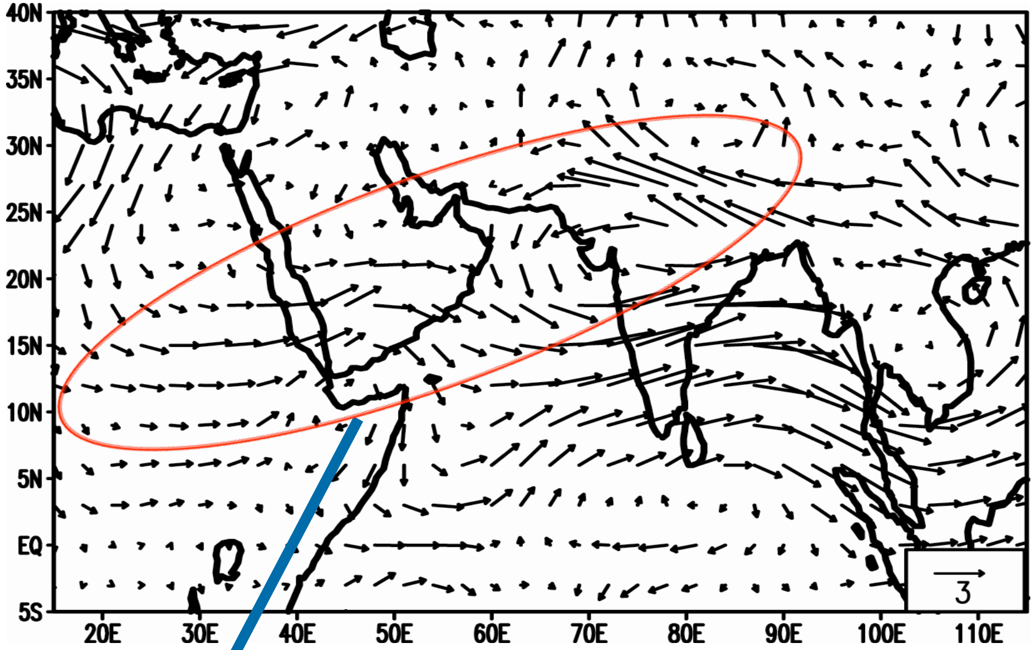
Dynamical response of monsoon trough during active monsoons

Vertical development of cyclonic circulation well above the mid-troposphere !

Relative vorticity (x10^{-6} s^{-1}) averaged over monsoon trough



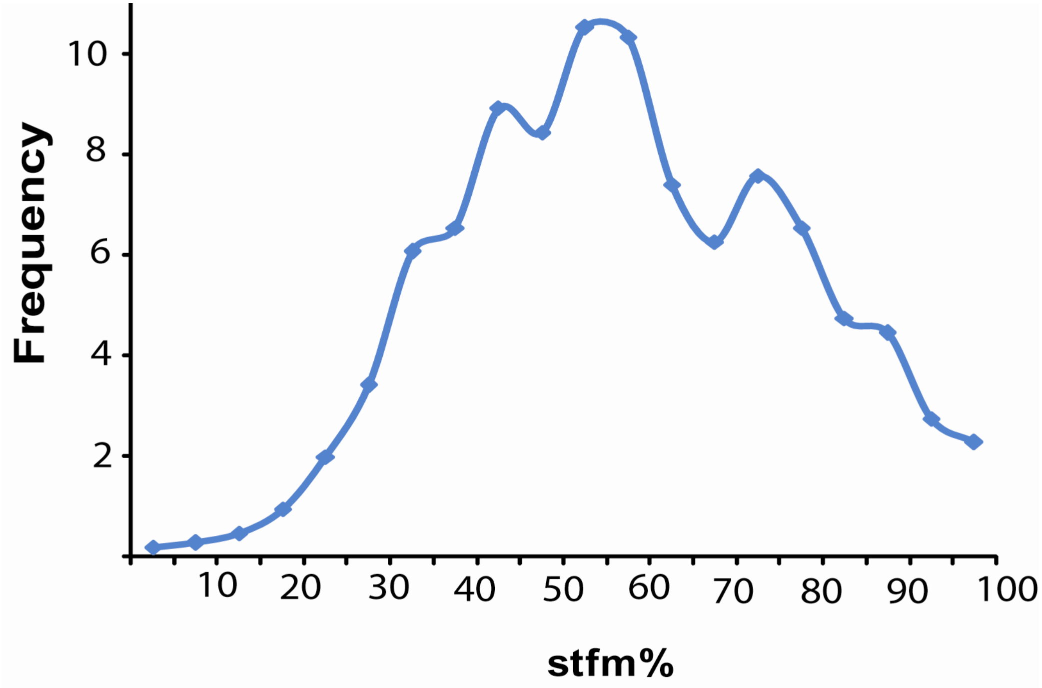
Wind anomaly at 500 hPa during active monsoons



Large-scale mid–level circulation anomalies extending into the African ITCZ region

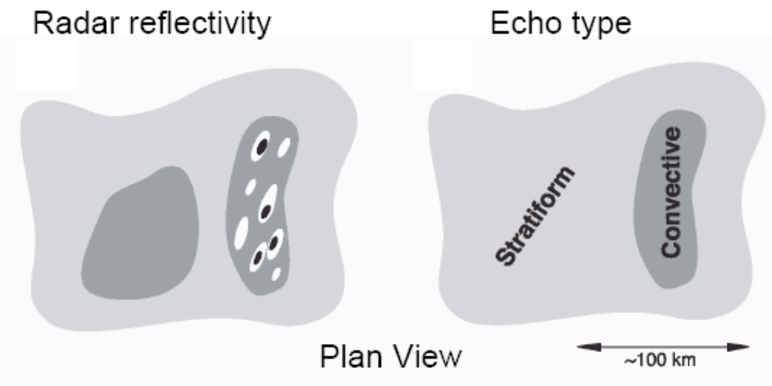
Ayantika Dey Choudhury and [illegible] Krishnan (2011): Dynamical response of the South Asian monsoon trough to latent heating from stratiform and convective precipitation, *J. [illegible] Sci.*, 68, 1347-1363.

Frequency distribution of stratiform/convective precipitation during active monsoon from TRMM PR

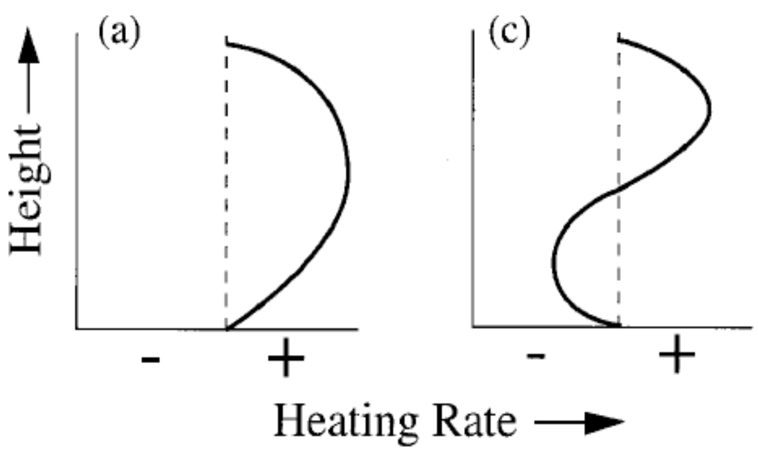


Eg. Large population of Nimbostratus clouds associated with monsoon depressions (Ref: Stano et al. 2002)

Role of latent heating from convective/stratiform cloud populations on the large-scale dynamical response of the Monsoon Trough ?



Vertical profiles of latent heating for convective and stratiform clouds



(Houze 1997)

Convective-

✓from young, active convection

✓w ~ several m/s

✓single mid-tropospheric heating peak

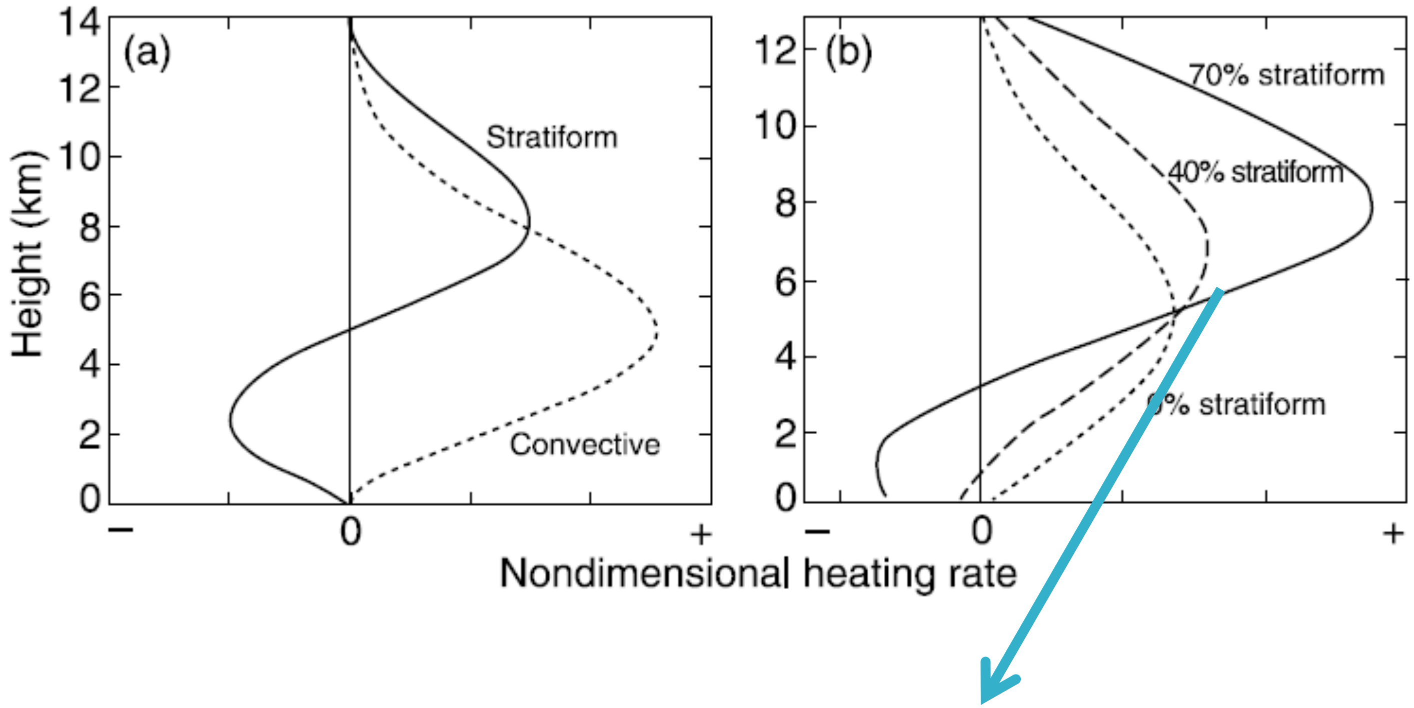
Stratiform–

✓from older and less active convetion

✓w~ <1-2m/s

✓upper tropospheric heating and lower tropospheric cooling

Calculation of vertical profiles of heating
(based on Schumacher et al. 2004)



Strong vertical gradient of heating in stratiform clouds

Assumed latent heating profiles associated with stratiform and convective precipitation are linearly combined based on the rain fraction for each precipitation type, normalized such that the area under the curve equals one, and then multiplied by the precipitation at each location

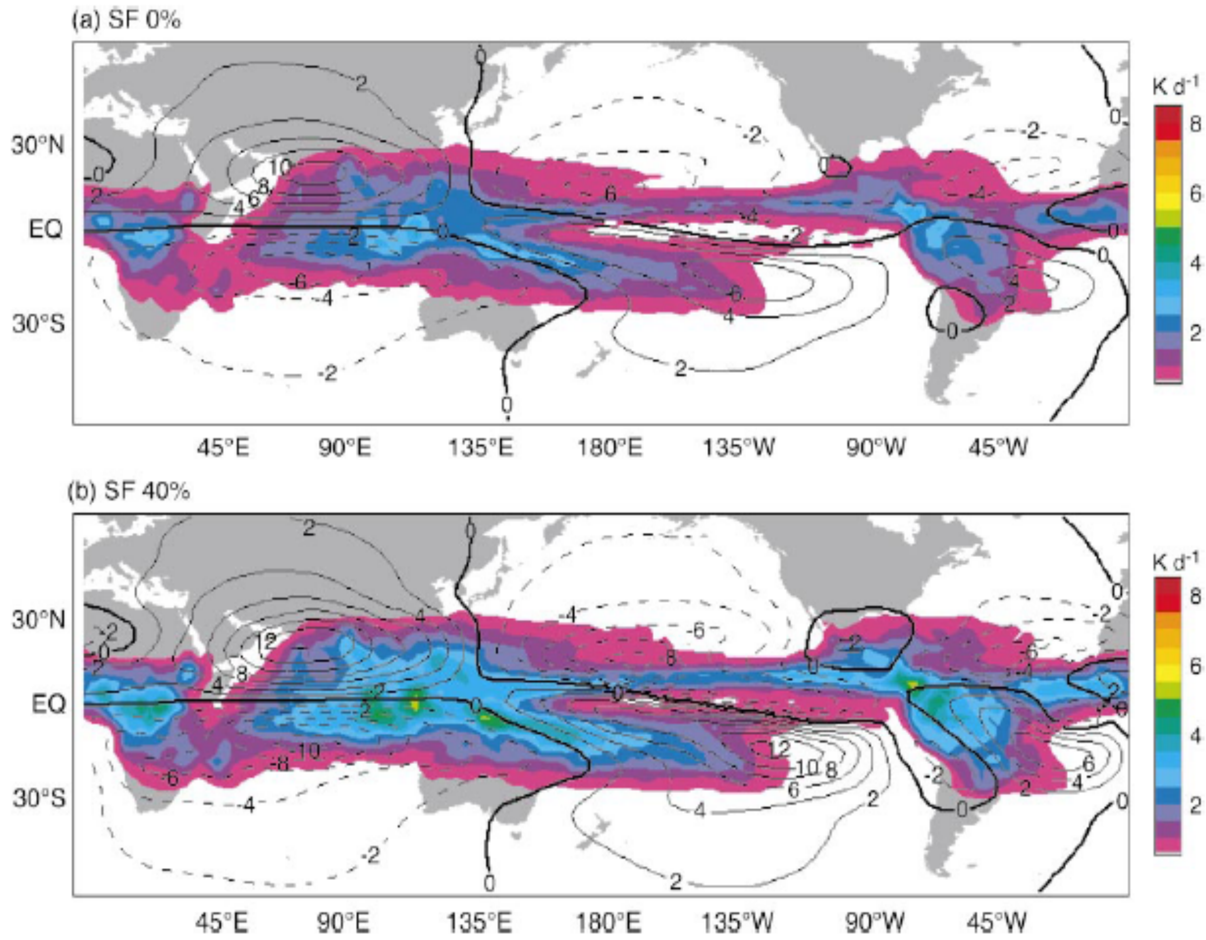
Response of the tropical Walker circulation to varying stratiform rain fractions

Upper tropospheric circulation response

C. Schumacher, R.A. Houze and I. Kraucunas (2004) – J. Atmos. Sci, 61, 1341-1358

250 hPa streamfunction anomaly and 400 hPa annual latent heating

Intensification of upper level circulation centers with increasing stratiform fraction (SF)



SF = 0%

SF = 40%

How does the South Asian monsoon trough respond to varying populations of convective and stratiform latent heating ?

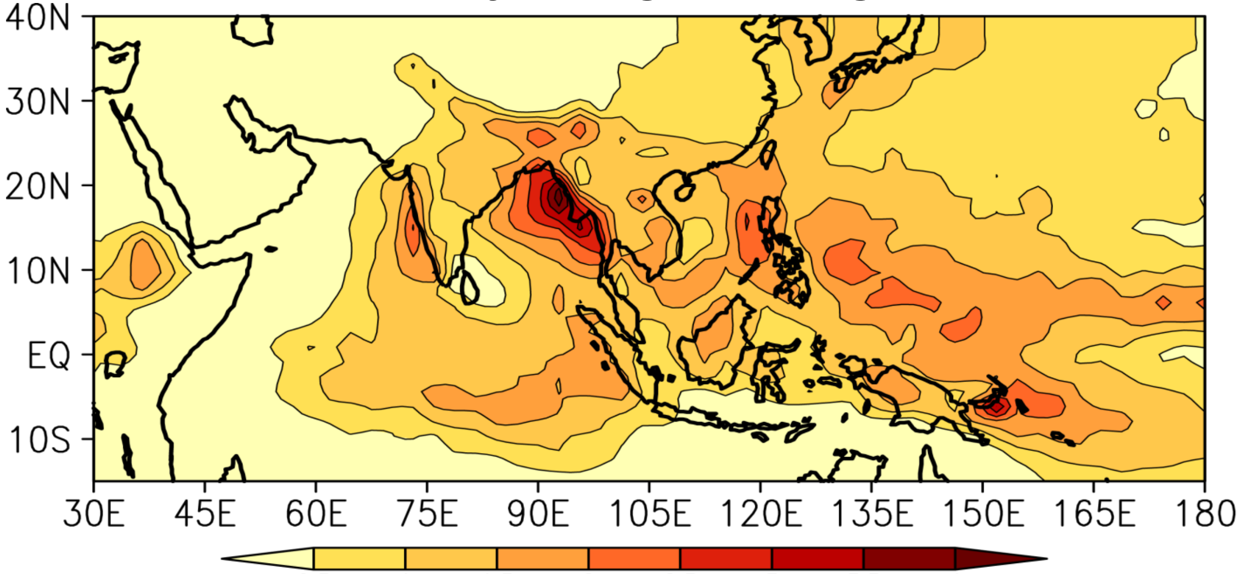
GCM experiments

- ❑Global atmospheric model with specified heating (adiabatic model)
- ❑Horizontal resolution - R40 , vertical resolution - 25 σ-levels
- ❑3D latent heating profiles are constructed based on observed TRMM rainfall and rain fractions (PR)
- ❑Steady state response: 100 days of model run with prescribed heating and damping (Rayleigh friction and Newtonian cooling with 5 days e-folding decay time-scale)

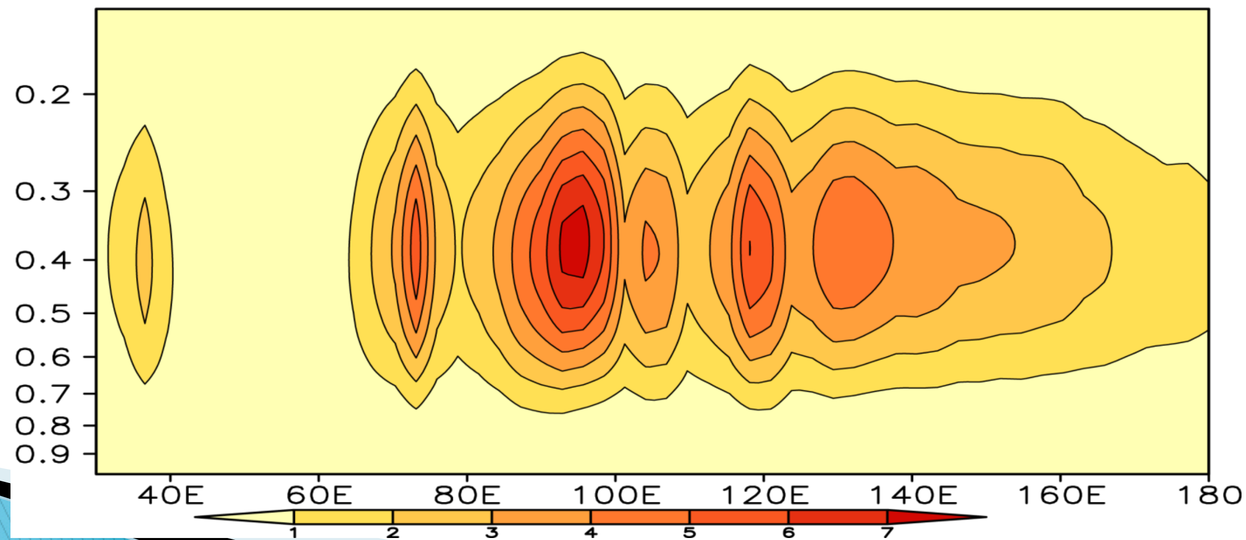
Ayantika Dey Choudhury and R. Krishnan (2011): Dynamical response of the South Asian monsoon trough to latent heating from stratiform and convective precipitation, *J. Atmos. Sci*, 68, 1347-1363.

Climatological JJAS latent heating derived from TRMM 3A25 rainfall

Vertically averaged heating



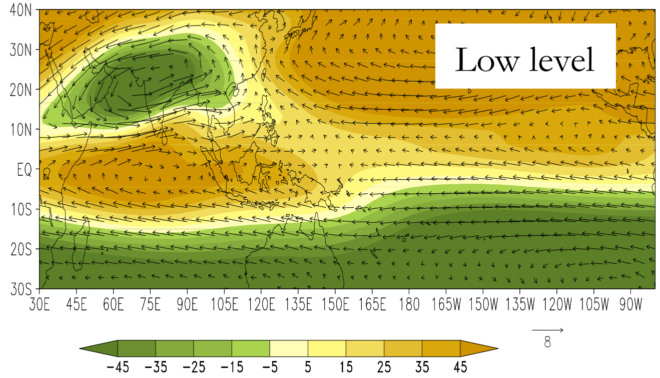
Height-longitude section (10N-20N)



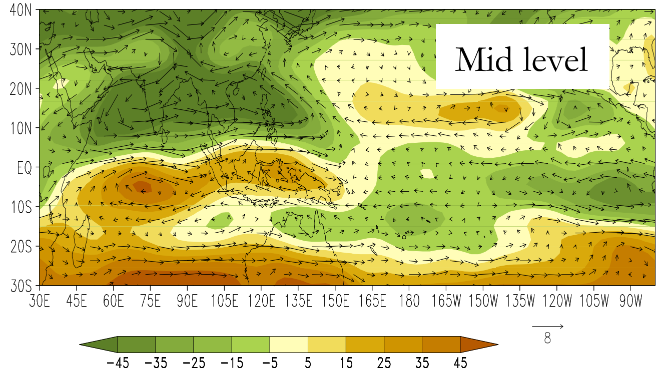
(Algorithm from Schumacher 2004)

Model response: Control (CTL) experiment

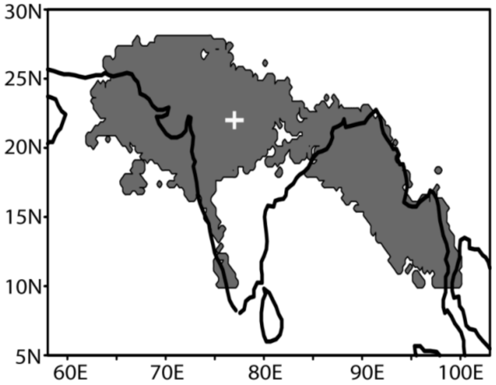
Winds and streamfunction



Monsoon Trough



Sensitivity of circulation response to varying population of convective and stratiform rain anomalies over the monsoon trough zone during active monsoon spells



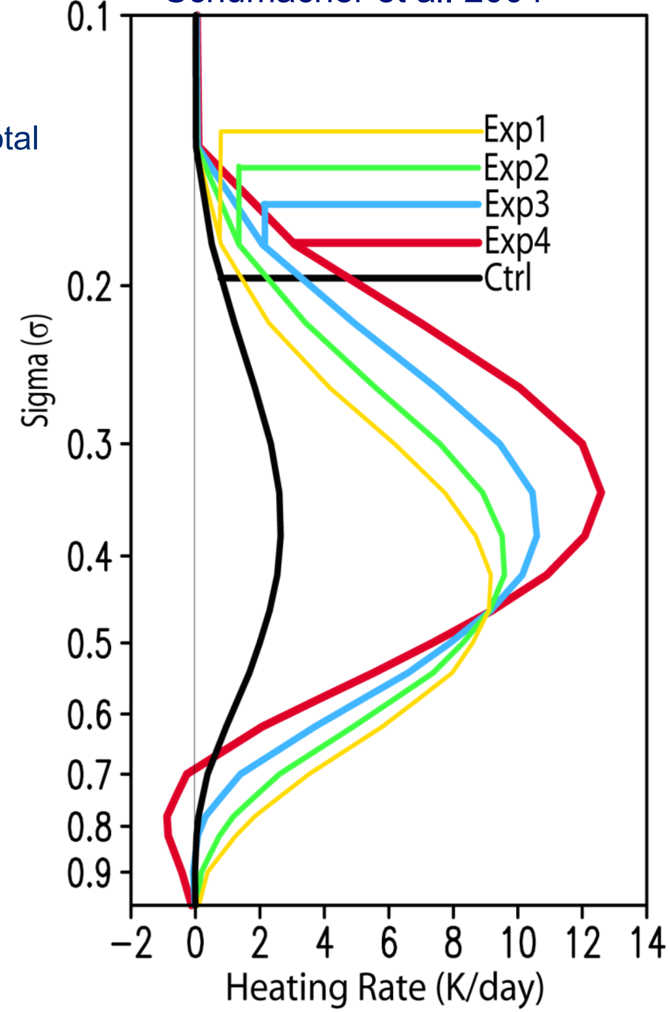
Shaded area: Monsoon trough (MT) zone

SF and CF of rainfall anomaly is assumed to be fixed at all grid points over the MT zone for any particular experiment

Total Rain = Clim Rain + Anom Rain

Spatial variation of CF and SF for the total rainfall over the MT zone is allowed

Heating profiles for sensitivity experiments computed based on Schumacher et al. 2004

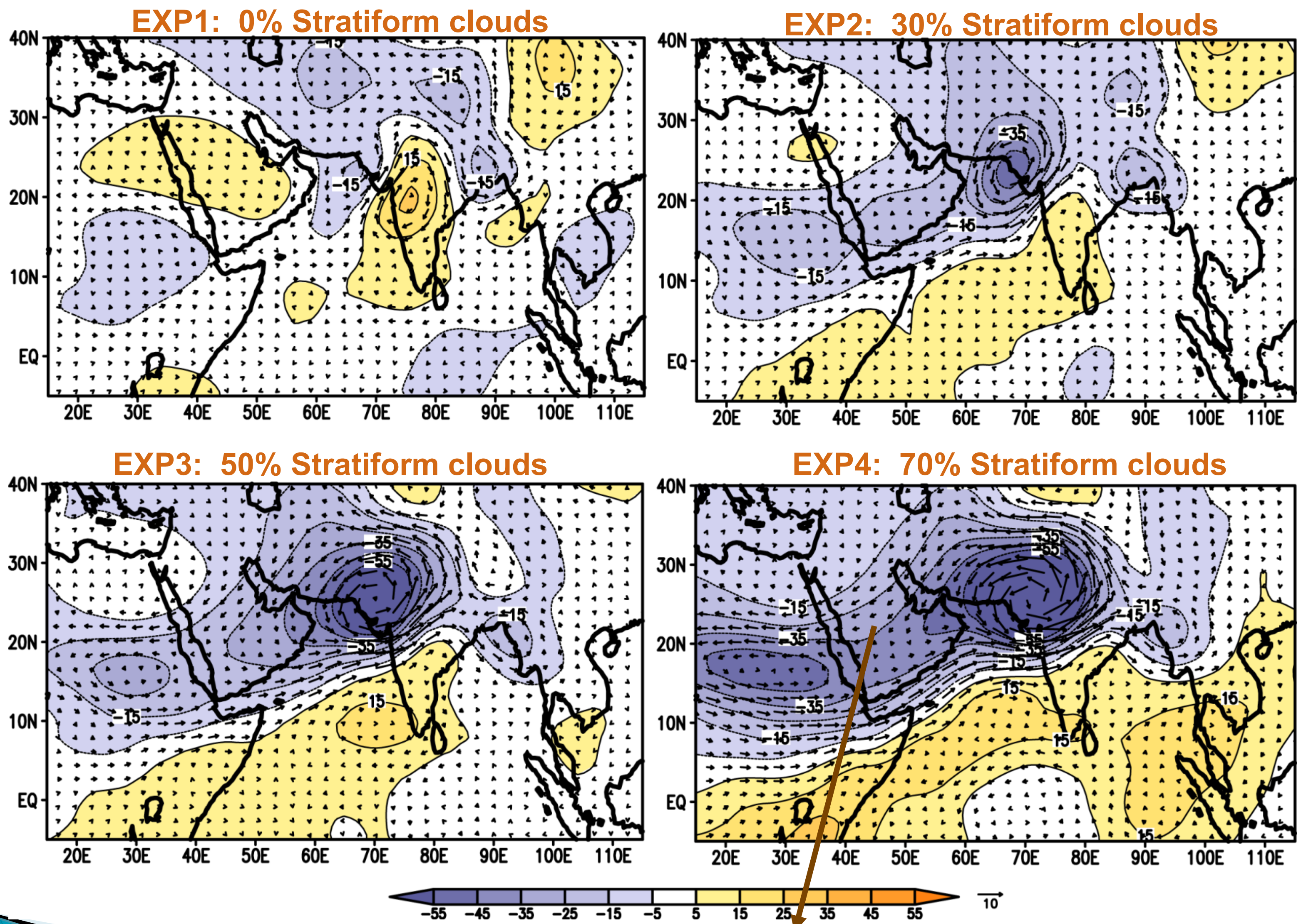


Model sensitivity experiments

Exp	Stratiform and convective fractions of rain anomaly during active monsoon period		Active period rain anomaly	
	Stratiform Fraction (SF)	Convective Fraction (CF)	Stratiform anomaly	Convective anomaly
Exp 1	0%	100%	0.0 % of Rain anomaly	100 % of Rain anomaly
Exp 2	30%	70%	30 % of Rain anomaly	70 % of Rain anomaly
Exp 3	50%	50%	50 % of Rain anomaly	50 % of Rain anomaly
Exp 4	70%	30%	70 % of Rain anomaly	30 % of Rain anomaly

Mid-level anomalous circulation response

Winds and stream function



Large scale structure of mid-level cyclonic response extending into African ITCZ region

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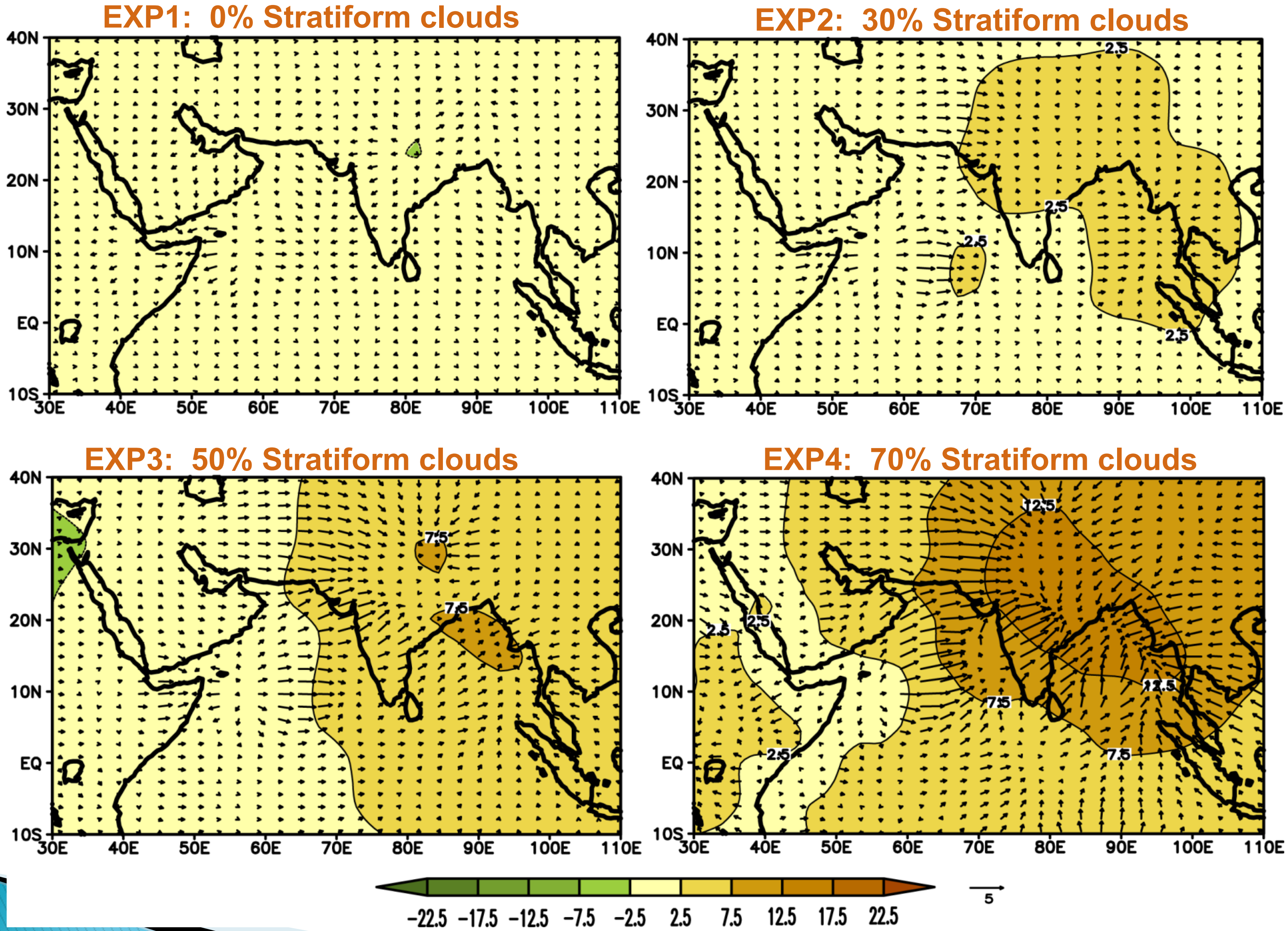
Mid-level anomalous circulation response

Divergent winds and velocity potential



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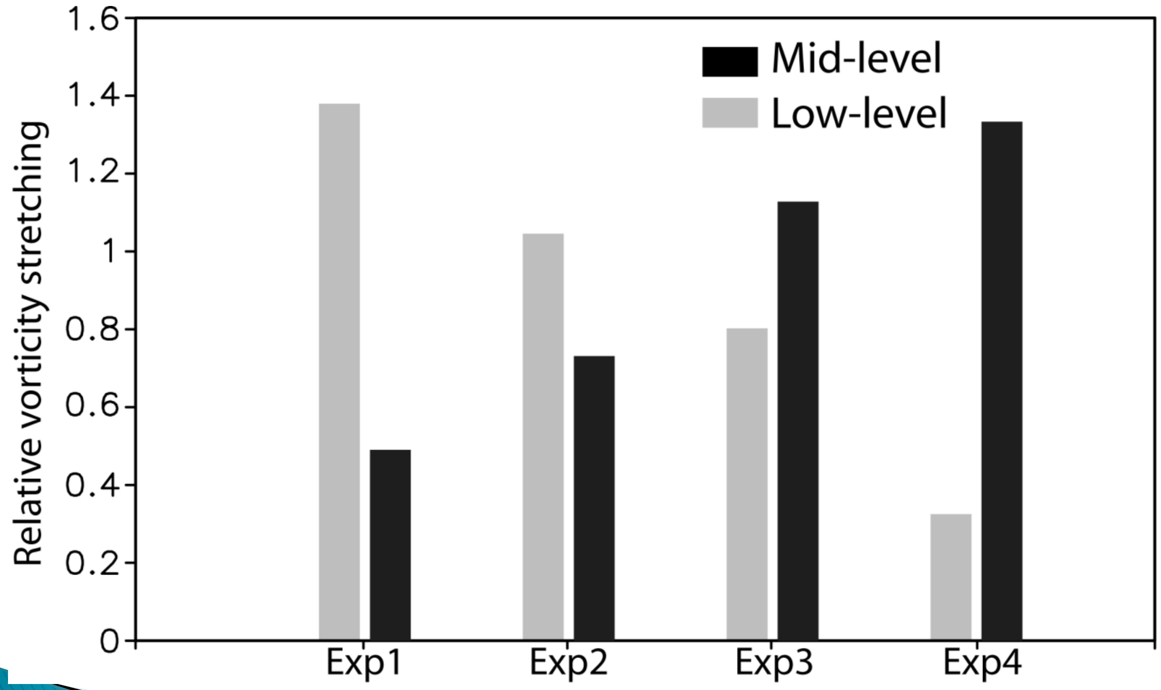
Vorticity equation in pressure coordinates

$$\frac{d(\varsigma + f)}{dt} = -(\varsigma + f)\nabla.V + \left\{\frac{\partial u}{\partial p}\frac{\partial \omega}{\partial y} - \frac{\partial v}{\partial p}\frac{\partial \omega}{\partial x}\right\}$$

Stretching Term **Twisting / Tilting Term**

Vorticity stretching at low and mid levels over the MT



Histogram showing low level (σ = 0.86, gray) and mid level (σ = 0.5, black) relative vorticity stretching (x 10^{-10} s^{-2}) averaged over the monsoon trough (18°N - 28°N, 70°E-90°E) for the four sensitivity experiments

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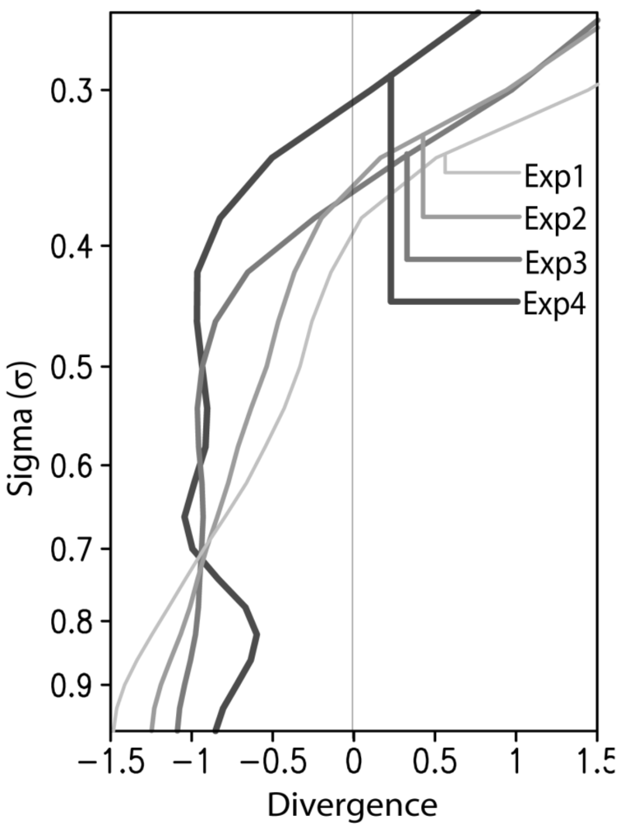
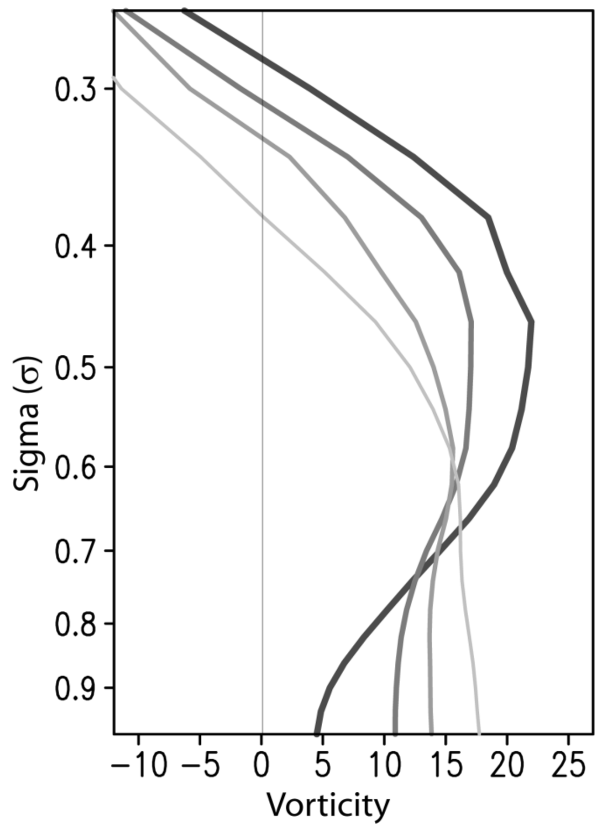
Vertical profiles of divergence



Vertical profiles of relative vorticity



EXP1: Rapid decrease of convergence in vertical

EXP4: Gradual build up of convergence in vertical

EXP4 : Large ∂Q/∂z

EXP1: Weaker mid and upper level cyclonic vorticity

EXP4: Intensification of cyclonic vorticity in mid levels and above

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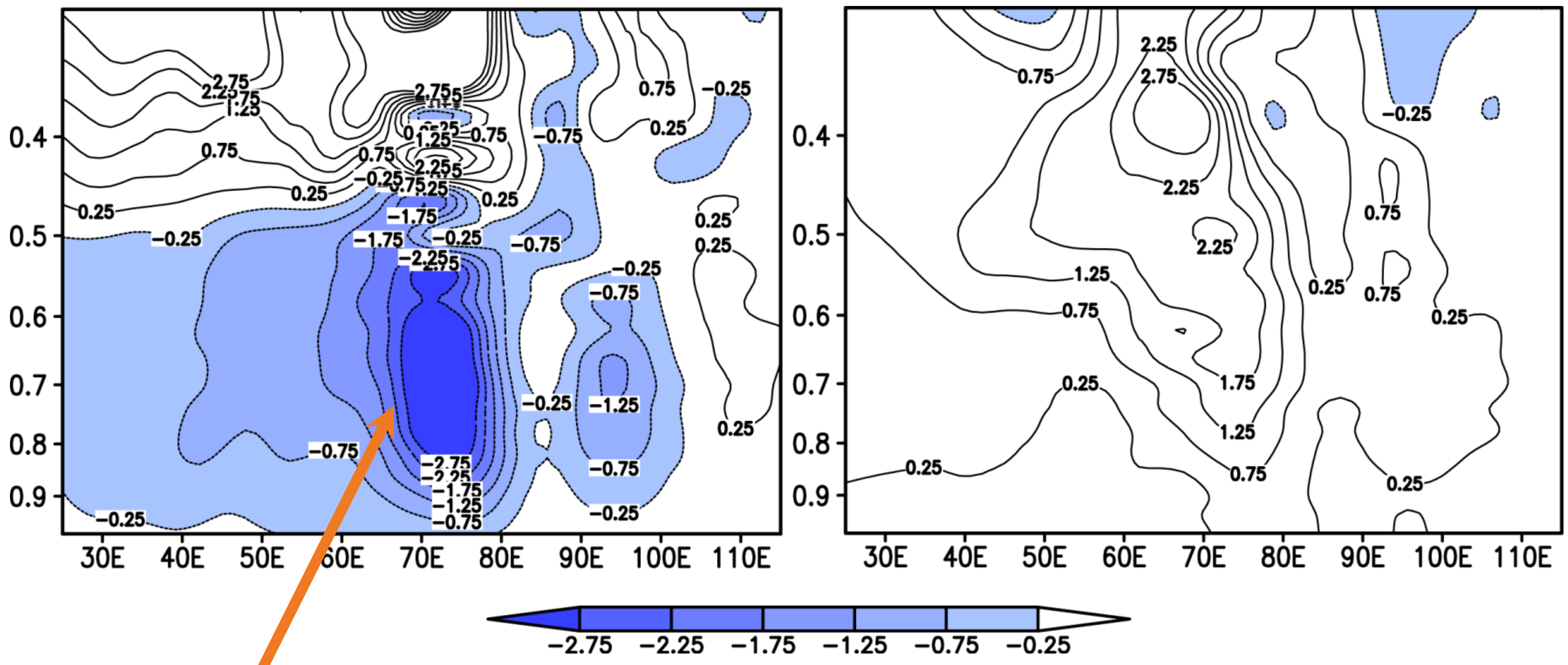
Dynamically forced uplift of layer of cyclonic vorticity over Monsoon Trough

- Imposed heating is positive
- Negative temperature anomaly is a clean indicator of dynamically forced uplift !

Longitude – height section of temperature anomalies averaged over 12N - 28N

EXP4: 70% STFM; 30% CONV

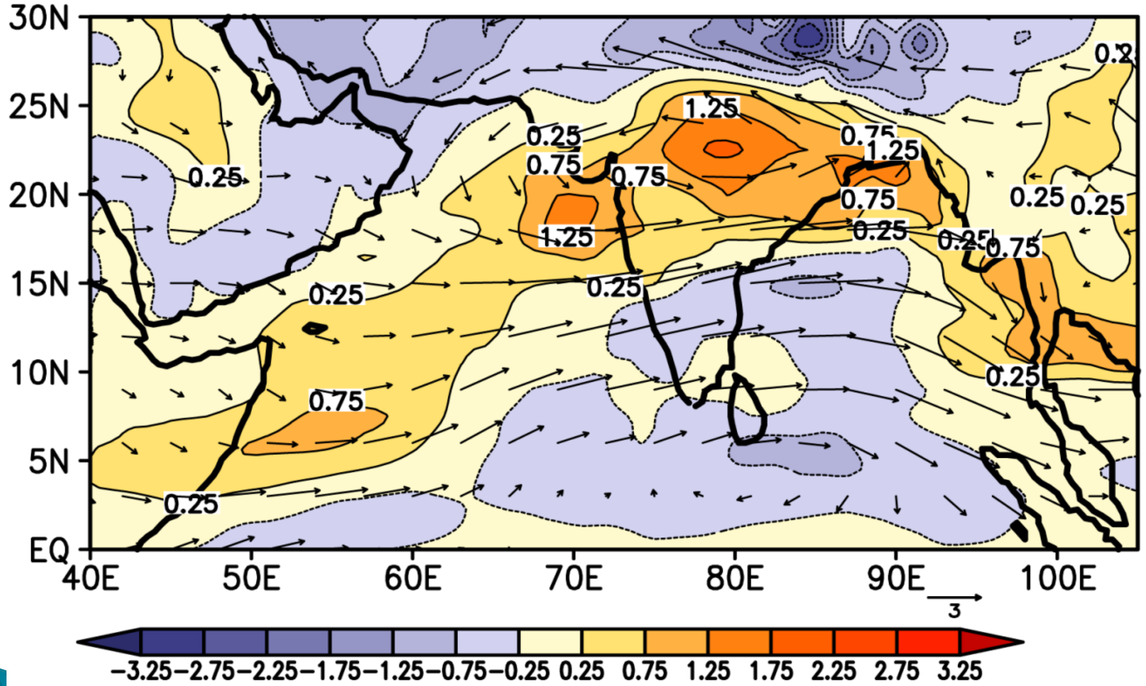
EXP1: 0% STFM; 100% CONV



Large scale cooling anomaly below mid-troposphere

Large-scale Rossby waves in mid-troposphere forced by monsoon heating

- Vertical gradient of heating over the precipitating regions of the tropics is a source of PV generation
- The circulation response is strongest at the level of maximum heating gradient
- The forced Rossby waves disperse PV westward



Anomaly composite of potential vorticity (PV x 10 $^{-7}$ kg m^2 s^{-1} K^{-1}) and winds (m s^{-1}) at the 330 K isentropic surface based on the active monsoon days. The data are based on ERA interim reanalysis

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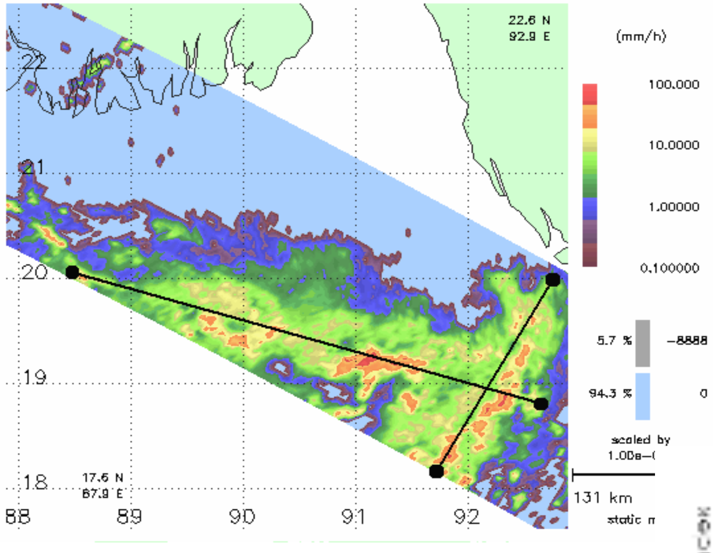
Summary

Vertical development of Monsoon Trough (MT) during active monsoons:

- Is not a localized phenomenon. It represents a large-scale dynamical response to organized MCS
- As the monsoon MCS evolves, the older portions of the MCS primarily composed of stratiform precipitation exert profound dynamical influence on the MT
- Latent heating from large population of stratiform clouds causes gradual build up of mid-level convergence and promotes vorticity stretching above the mid troposphere
- Vertical gradient of heating (PV source) is maximum near mid-troposphere for stratiform-type rain. This allows generation of strong PV in mid-levels
- Rossby waves disperse PV westward with long components of the forced response extending westward up to the African ITCZ
- MT is basically subjected to a forced dynamical uplift. Temperature response shows negative anomalies below 600 hPa
- There is need to improve moist convection parameterizations in GCMs, by taking into account realistic description of interactions between the MT dynamics and the MCS latent heating.0

Thank you


22.6 N
92.9 E
(mm/h)
100.000
10.0000
1.00000
0.100000
5.7 %
-8888
94.3 %
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scaled by
131 km
17.6 N
87.9 E
22
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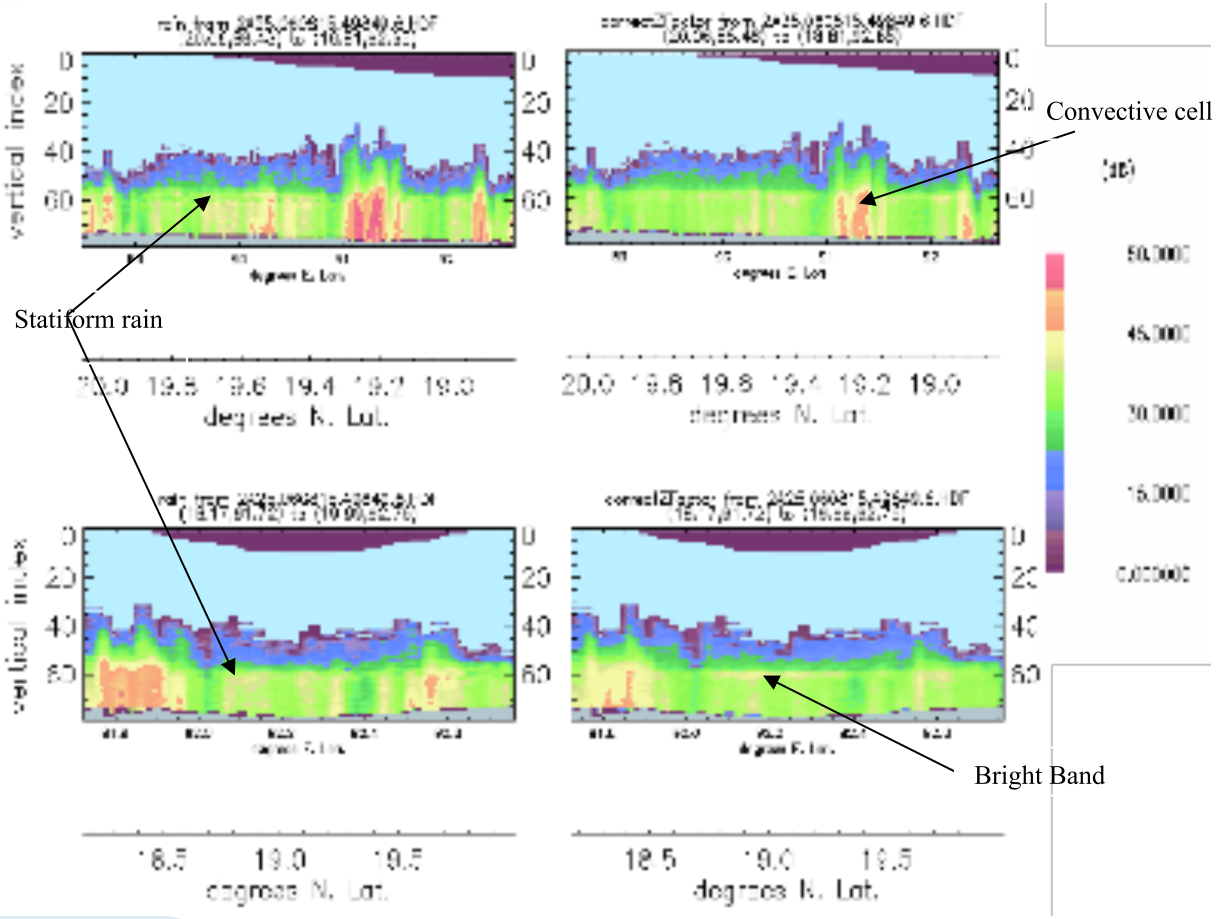
89
90
91
92


vertical index
Convective cell
Statiform rain
Bright Band
(dB)
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degrees N. Lat.
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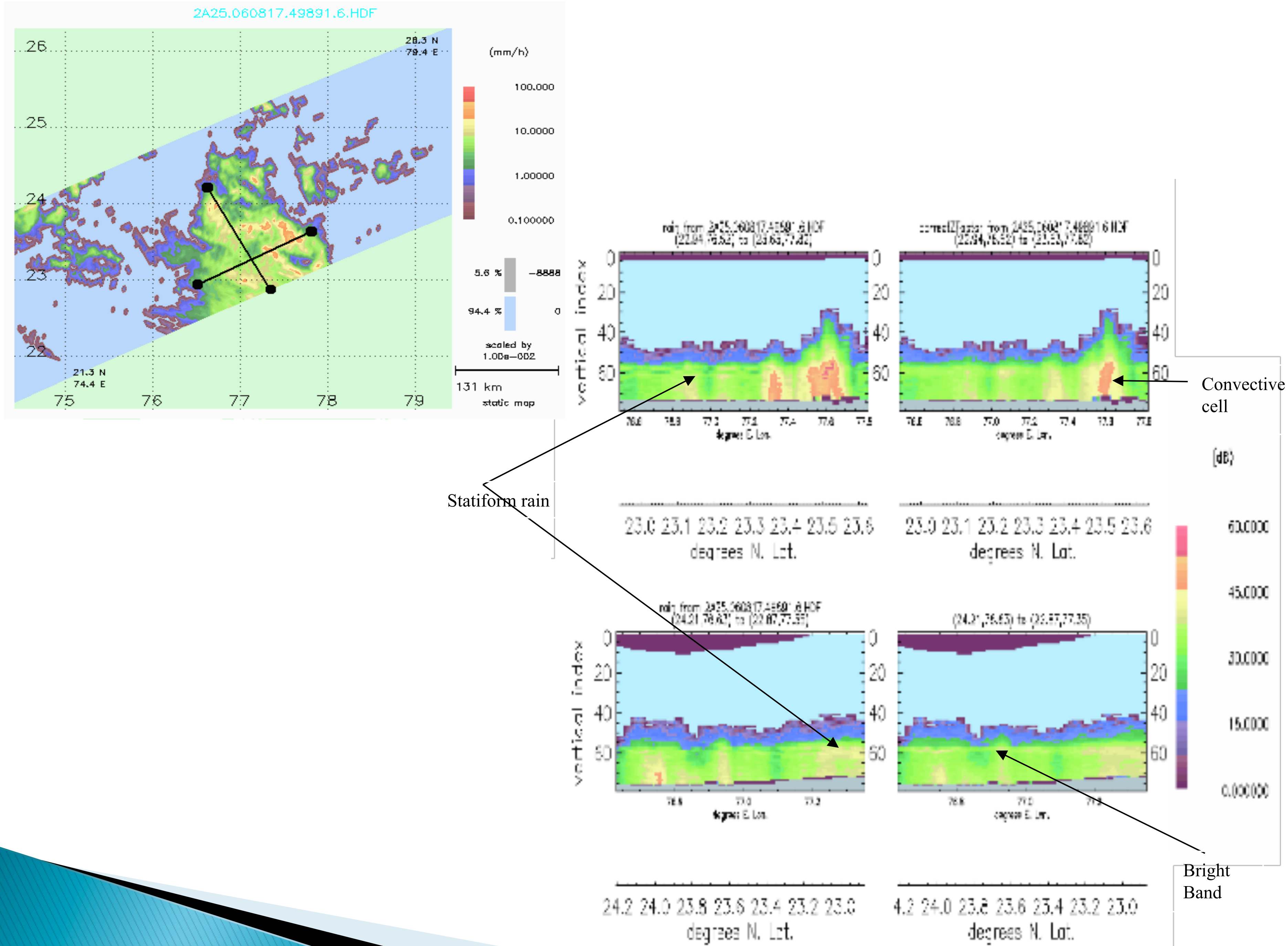

2A25.060817.49891.6.HDF
26.3 N
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21.3 N
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25
24
23
22
75
76
77
78
79
(mm/h)
100.000
10.0000
1.00000
0.100000
5.6 %
-8888
94.4 %
0
scaled by
1.00e-002
131 km
static map
vertical index
23.0 23.1 23.2 23.3 23.4 23.5 23.6
degrees N. Lat.
24.2 24.0 23.8 23.6 23.4 23.2 23.0
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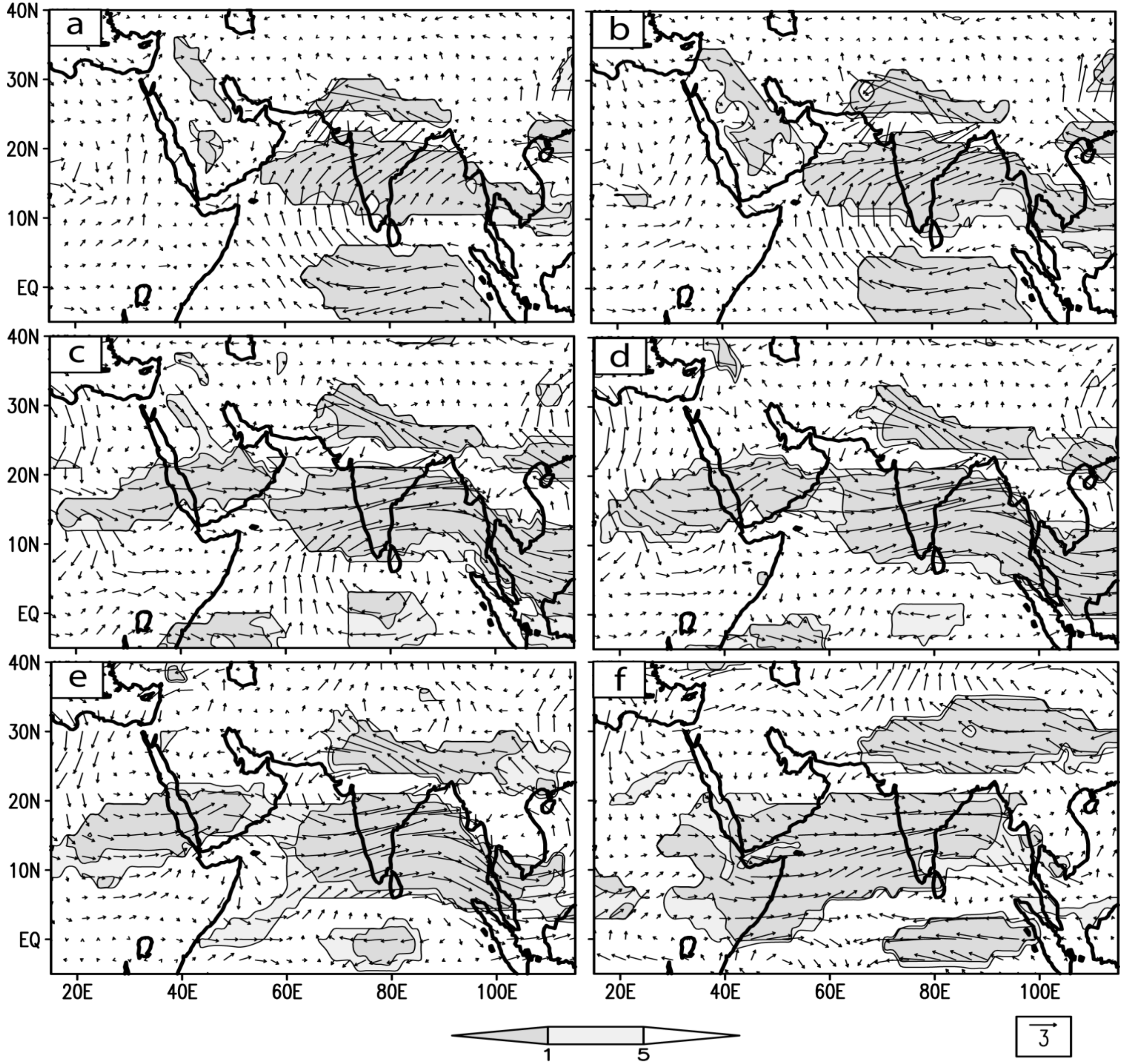

Fig.5 Wind anomaly (m s^{-1}) composites and statistical levels of significance of zonal wind anomaly based on active monsoon days **(a)** 925 hPa **(b)** 850 hPa **(c)** 700 hPa **(d)** 600 hPa **(e)** 500 hPa **(f)** 350 hPa. The shading denotes regions over which the zonal wind anomaly is statistically significant at 1% and 5% levels. The data is based on ERA-interim reanalysis.

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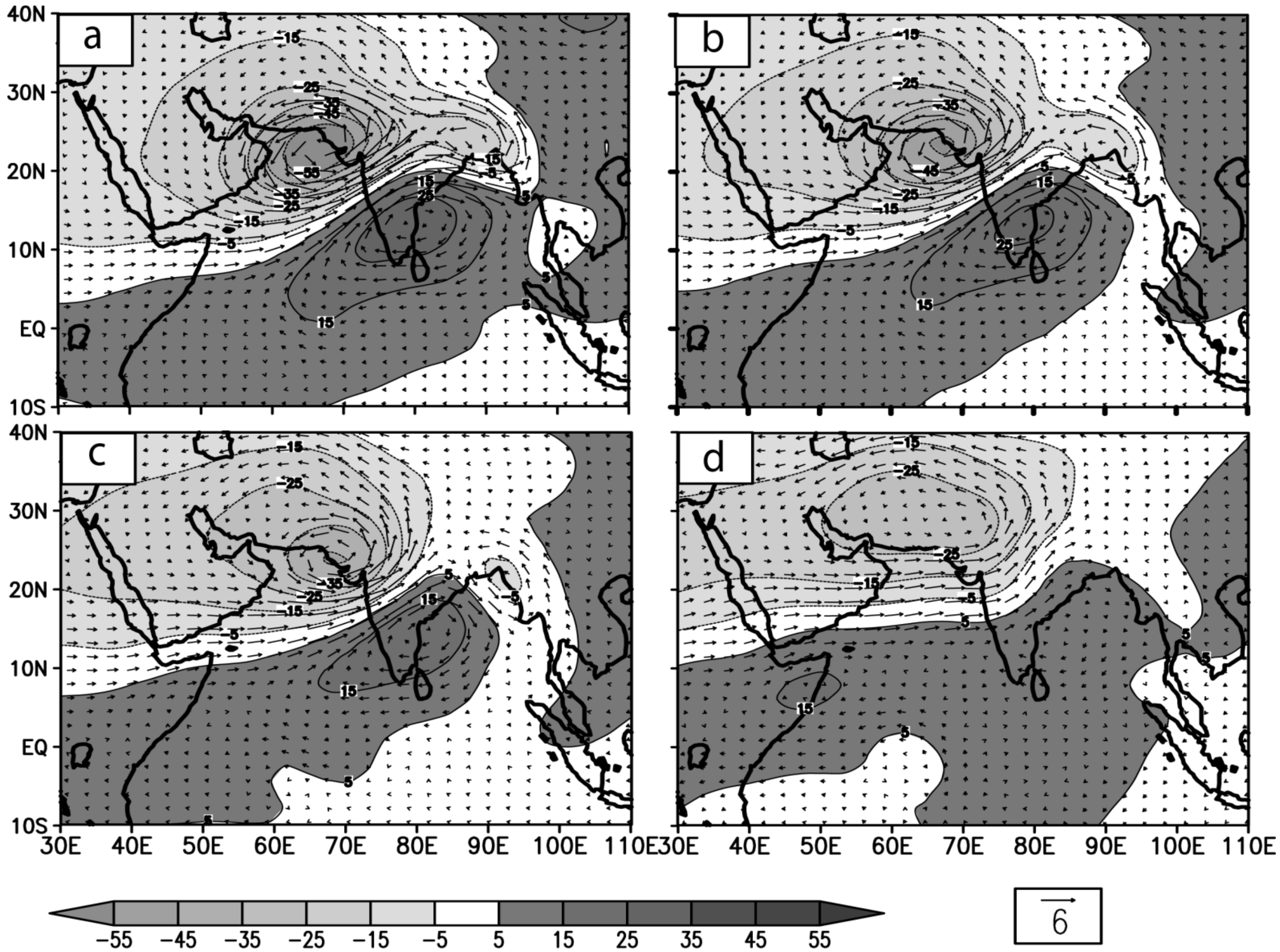

Fig.9 Model simulated low level (0.98sigma - 0.66sigma) anomalous response shown by wind (m s^{-1}) and streamfunction (x 10^{-5} m^2s^{-1}) anomalies for the 4 active monsoon experiments **(a)** Exp1 **(b)** Exp2 **(c)** Exp3 **(d)** Exp4

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