Process-based diagnostics for monsoon variability

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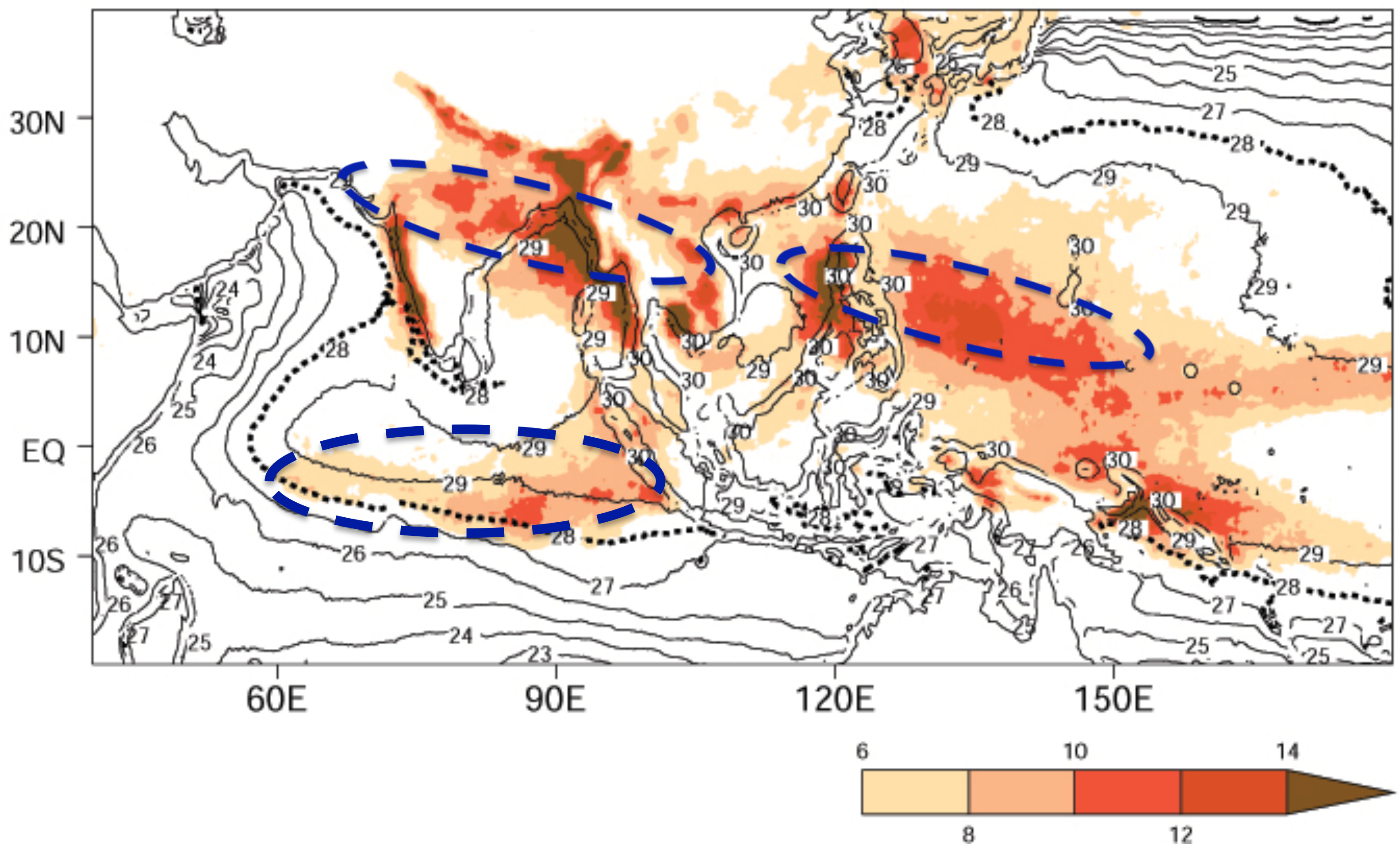
INTERNATIONAL PACIFIC RESEARCH CENTER

ICTP – TTA Lecture 16 June 2016

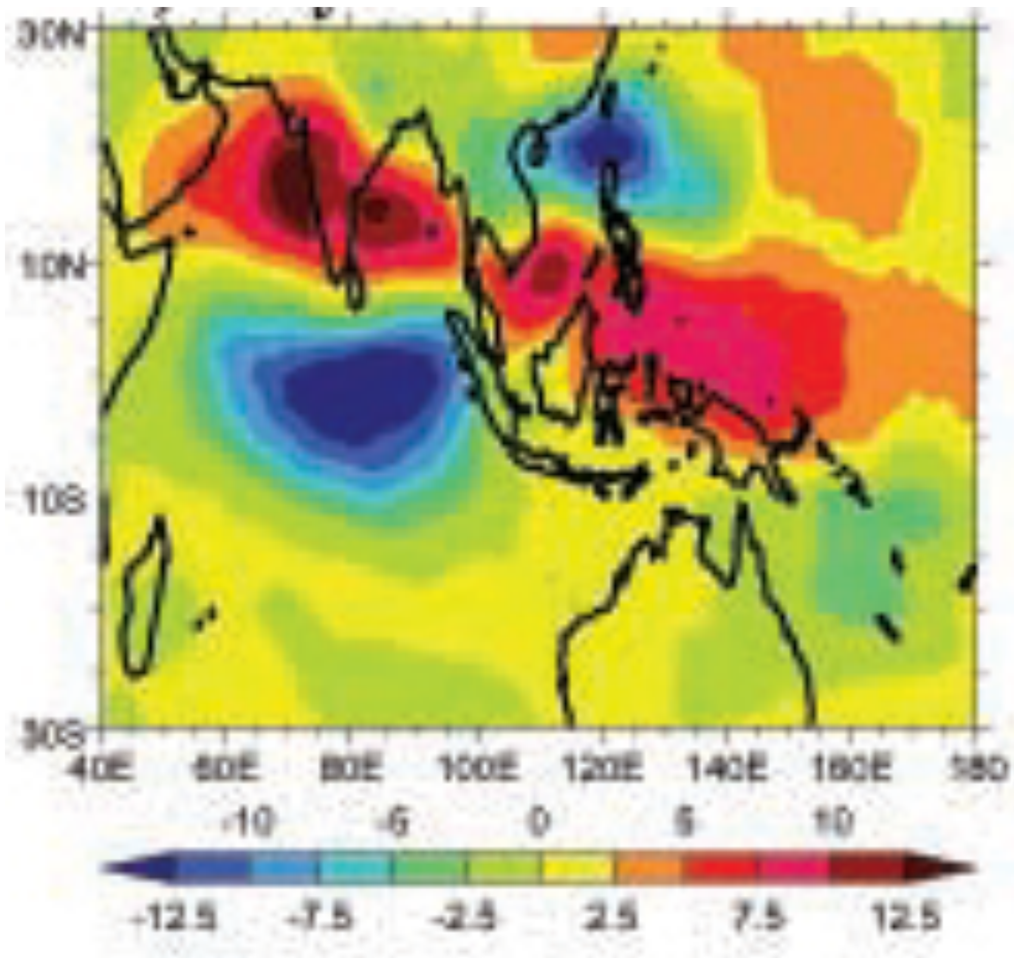
JJAS – Precipitation and SST Climatology



mm/day

- Multiple regional rainfall maxima -
- EIO and SPCZ – still experience high precipitation (thermal equator at 20°N)
- Central India rainfall – dynamical effects; Rain-shadow regions
- absolute ascent over a large domain

Observed Boreal Summer ISV



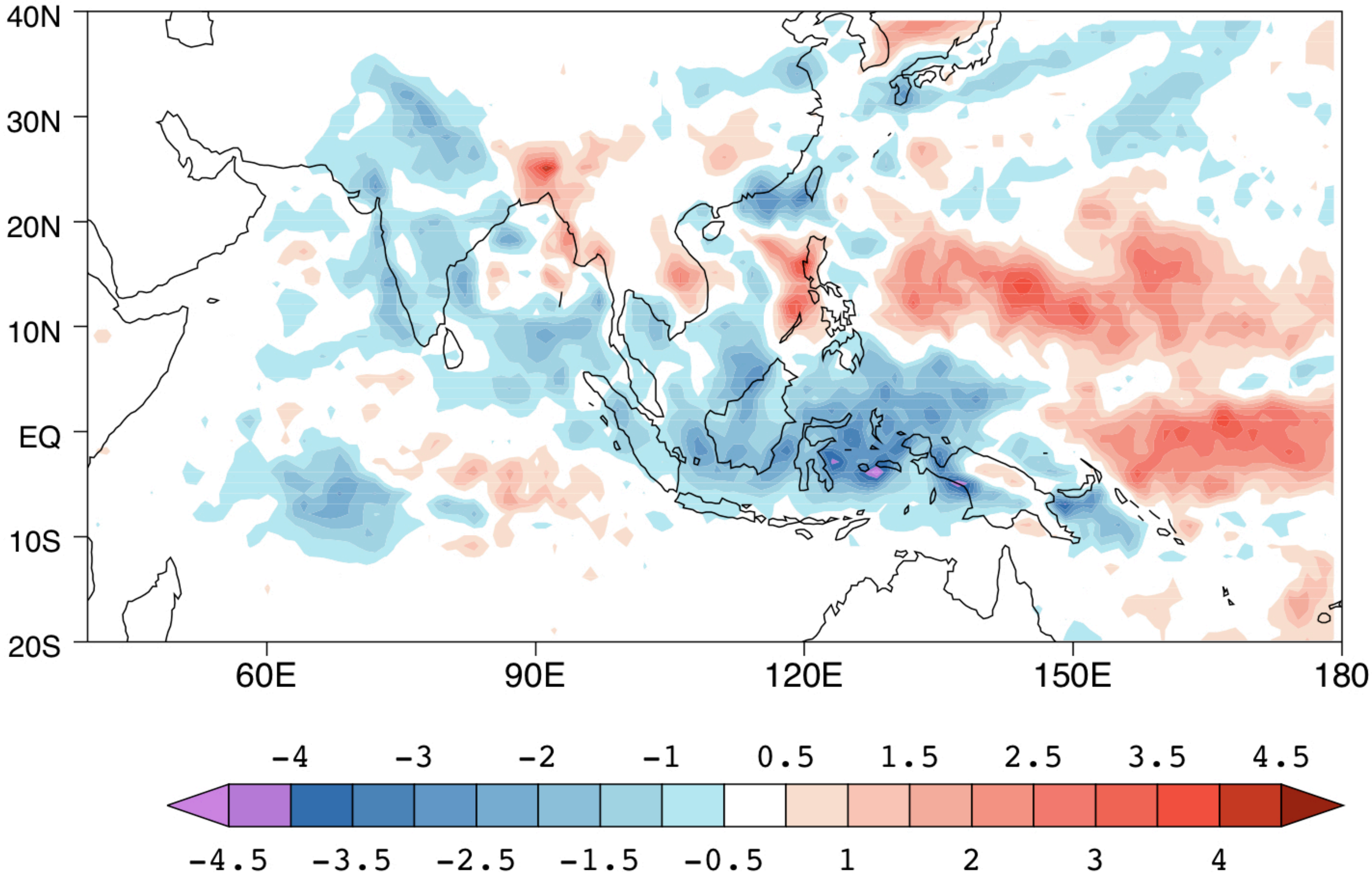
“internal dynamics”

OLR anomalies W/m^2

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

“one-phase of the ISV”

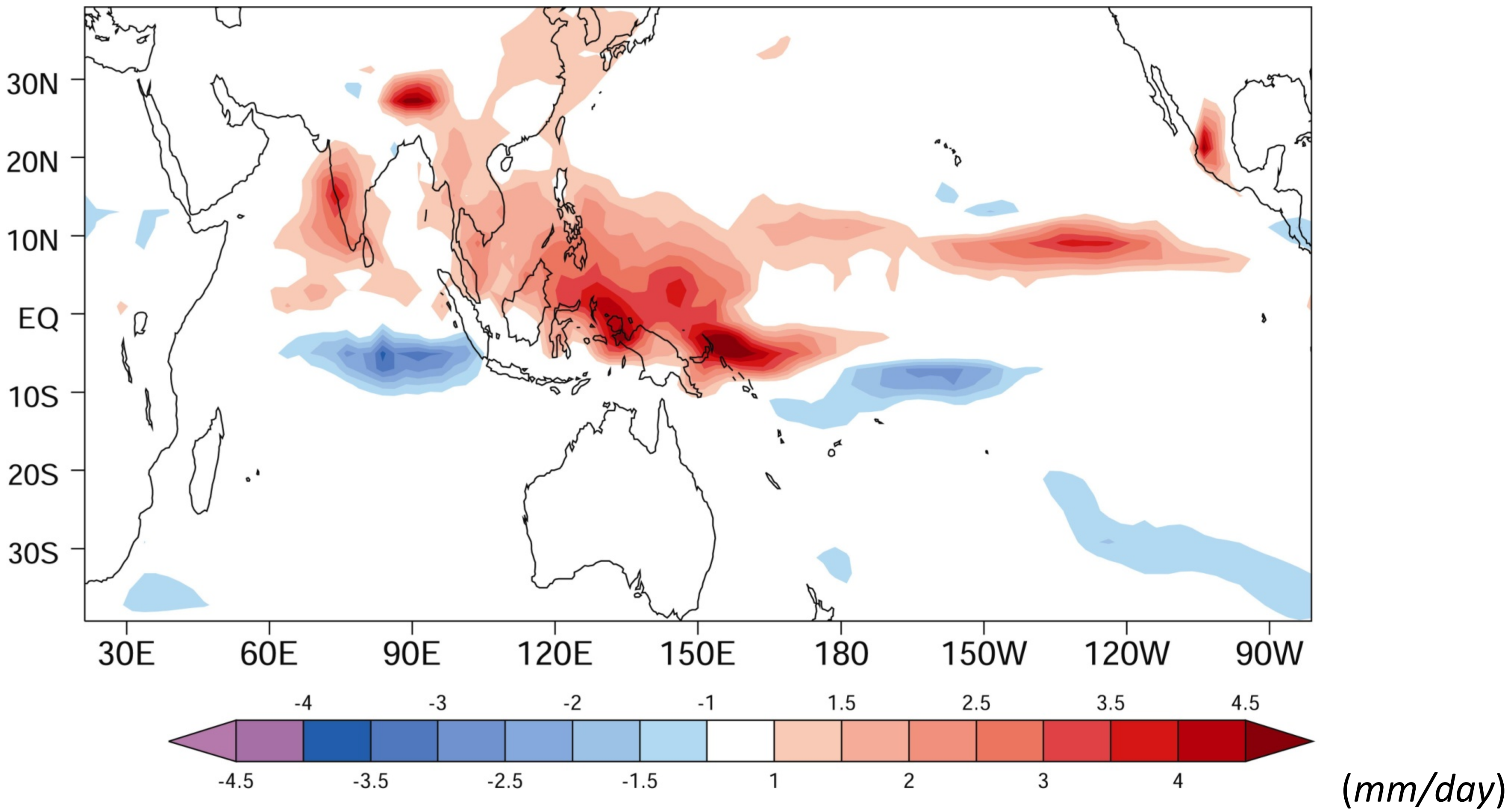
JJAS rainfall anomalies (2002/04/09) - TRMM



"Boundary forcing"

JJAS Precipitation response in CM_2.1

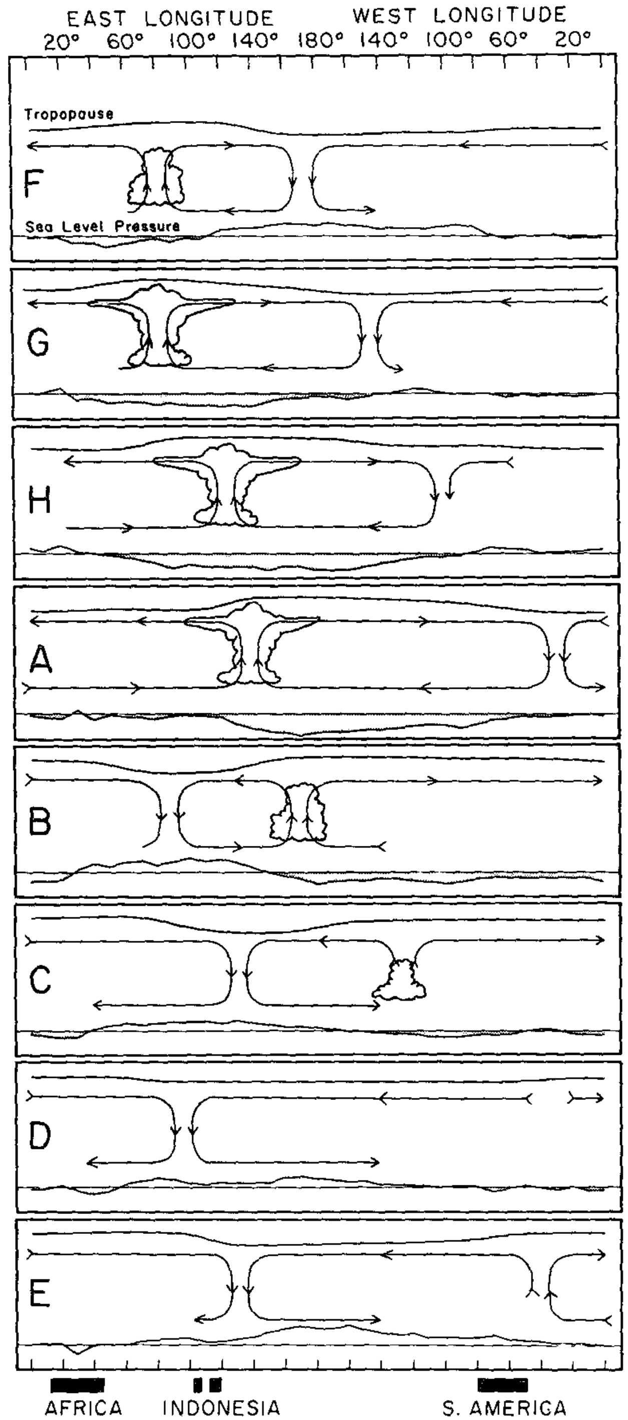
4xCO_2 *minus* 20c3m



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



Madden and Julian (1971, 1972, 1994)

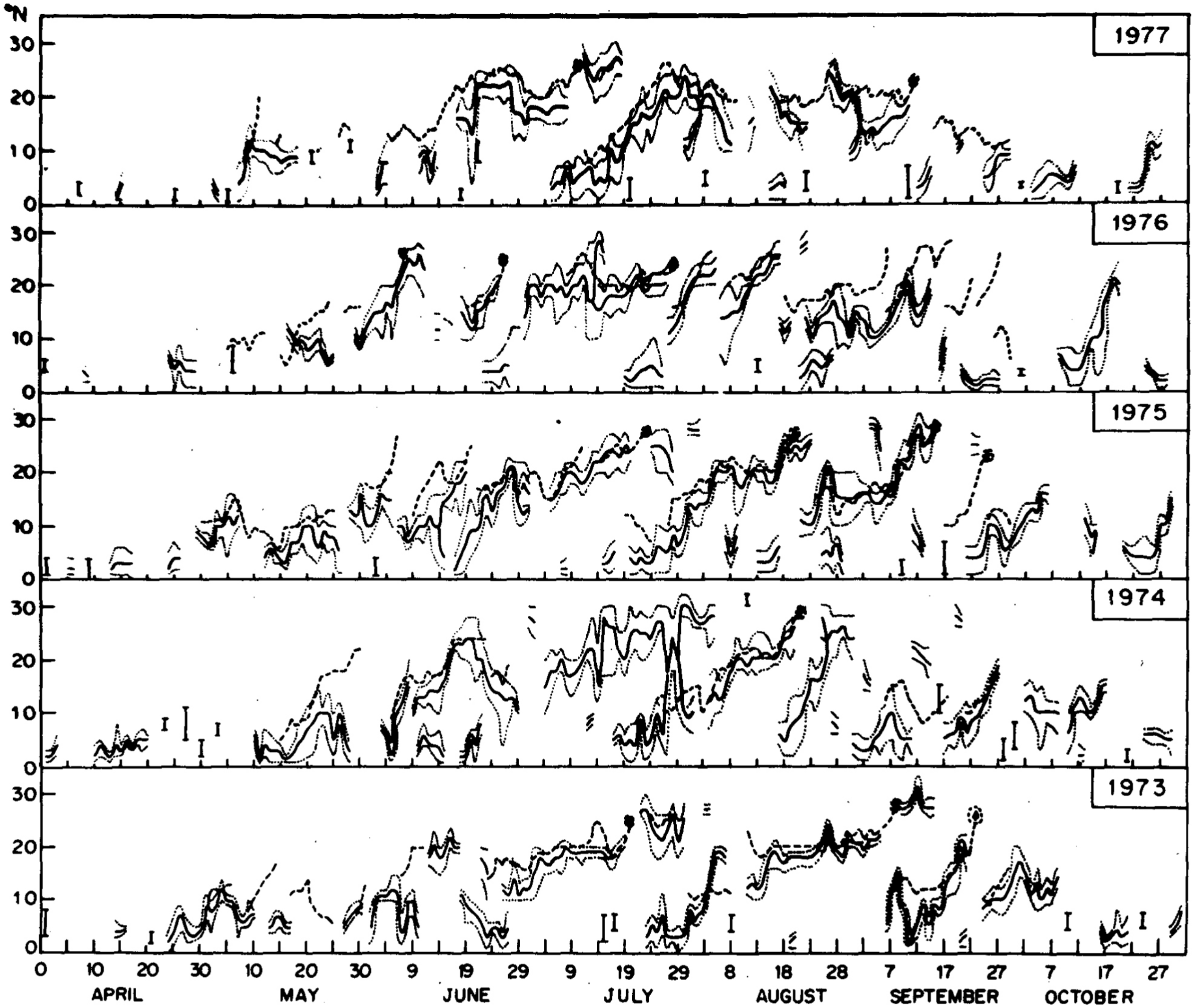


FIG. 4. Daily variation of the latitude of the axis of the MCZ (solid line); northern and southern limits (dotted line) of the MCZ; and the location of the 700 mb trough (dashed line) at 90°E during 1973–77.

Sikka and Gadgil (1980)

Yasunari 1979; 1980

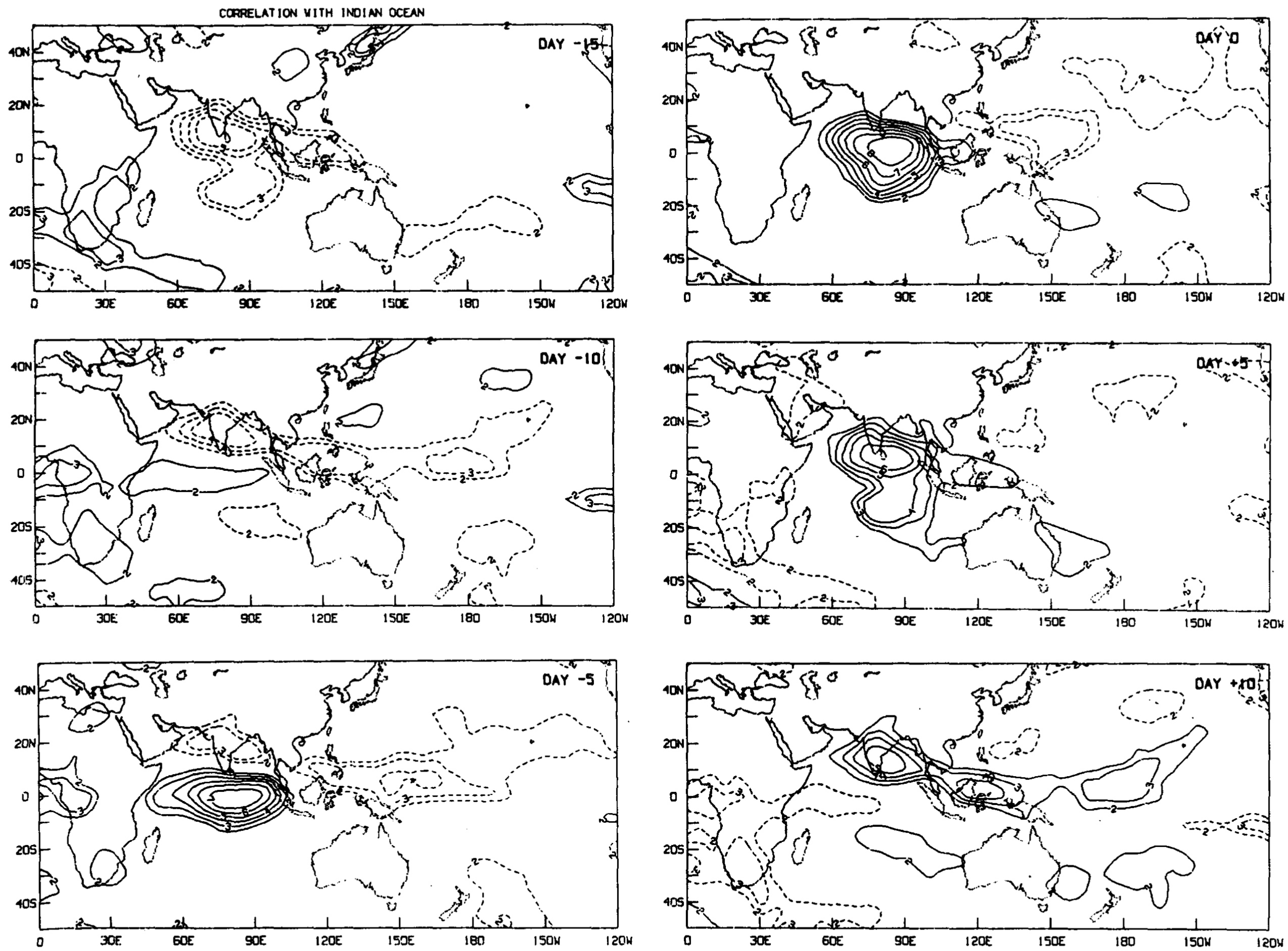


FIG. 5. One-point correlation maps of OLR from lags −15 to 10 days with respect to the Indian Ocean (5°S–5°N, 70°–85°E). Correlation coefficients have been multiplied by 10. The zero contours are omitted.

Lau and Chan 1986 (MWR)

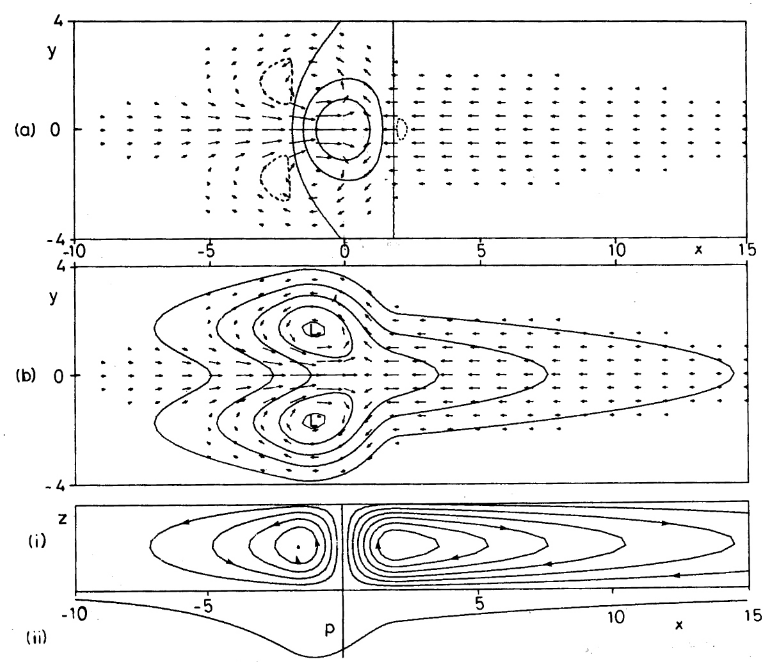


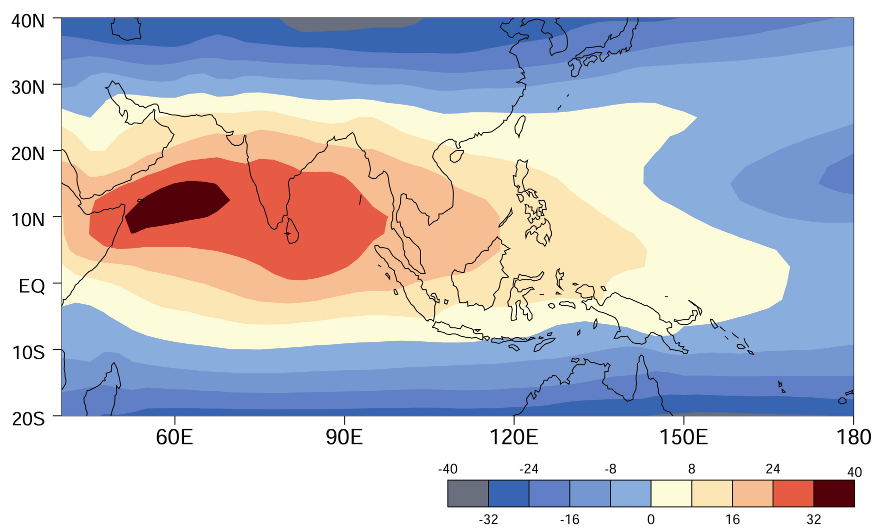
Figure 11: Solution of Gill's model for the case of heating symmetric about the Equator. The upper panel shows the heating field and the low-level wind field. The center panel shows the perturbation pressure field, which features low pressure along the Equator generally, with twin cyclones slightly off the Equator. The bottom panel shows the implied vertical motion and the zonal variation of the pressure along the Equator. From Gill (1980).

Gill (1980)

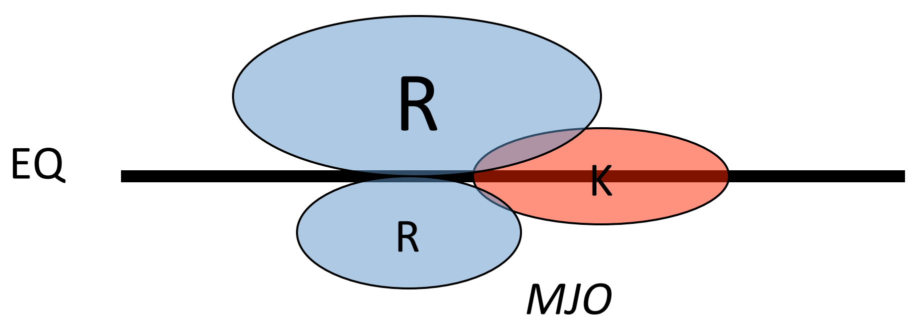
Hoskins and Wang (2006)

Mean Monsoon and Intraseasonal Variability

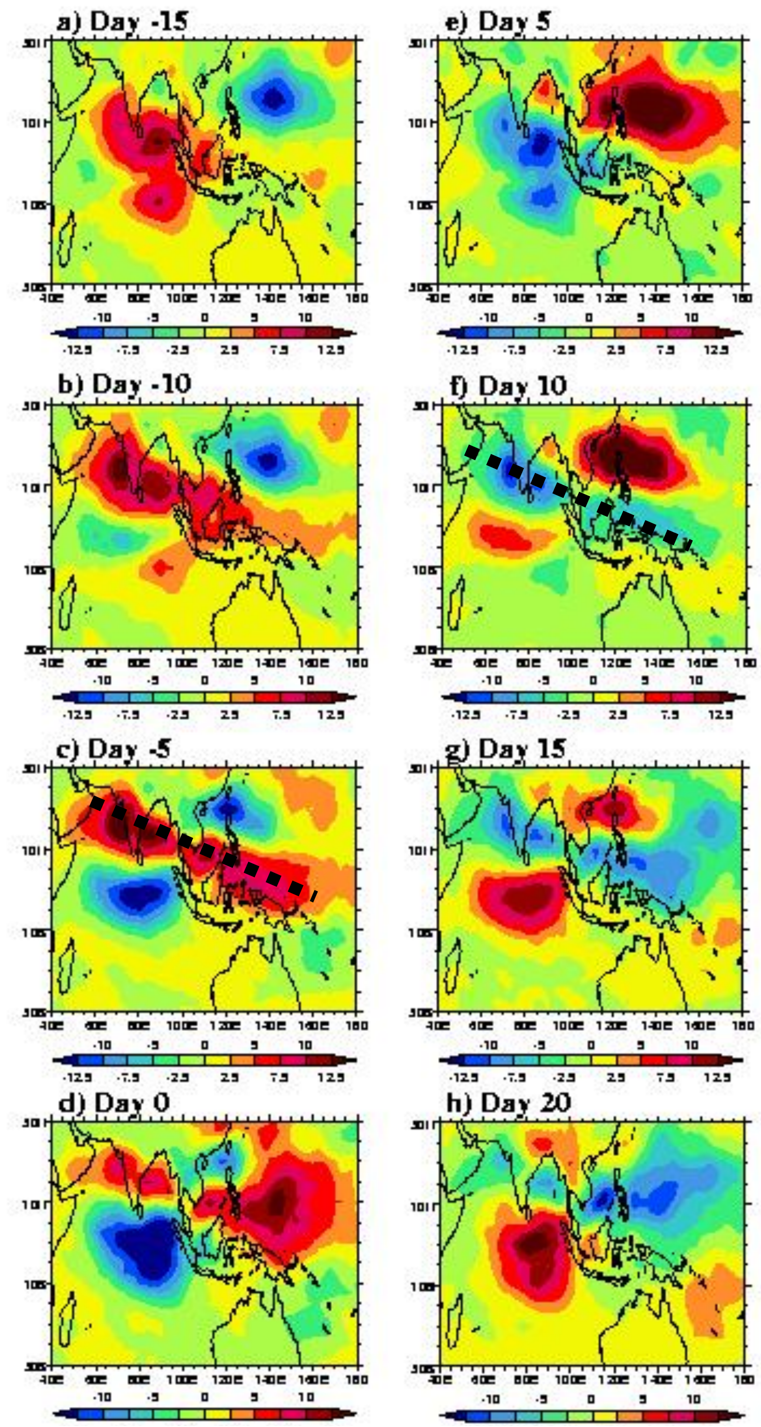
Zonal Vertical Shear



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



Initiation



Rossby-Kelvin packet

Poleward - India

Eastward – W. Pacific

Annamalai and
Sperber (2005)

“tilted rain band”

Poleward – W. Pacific

Amplification

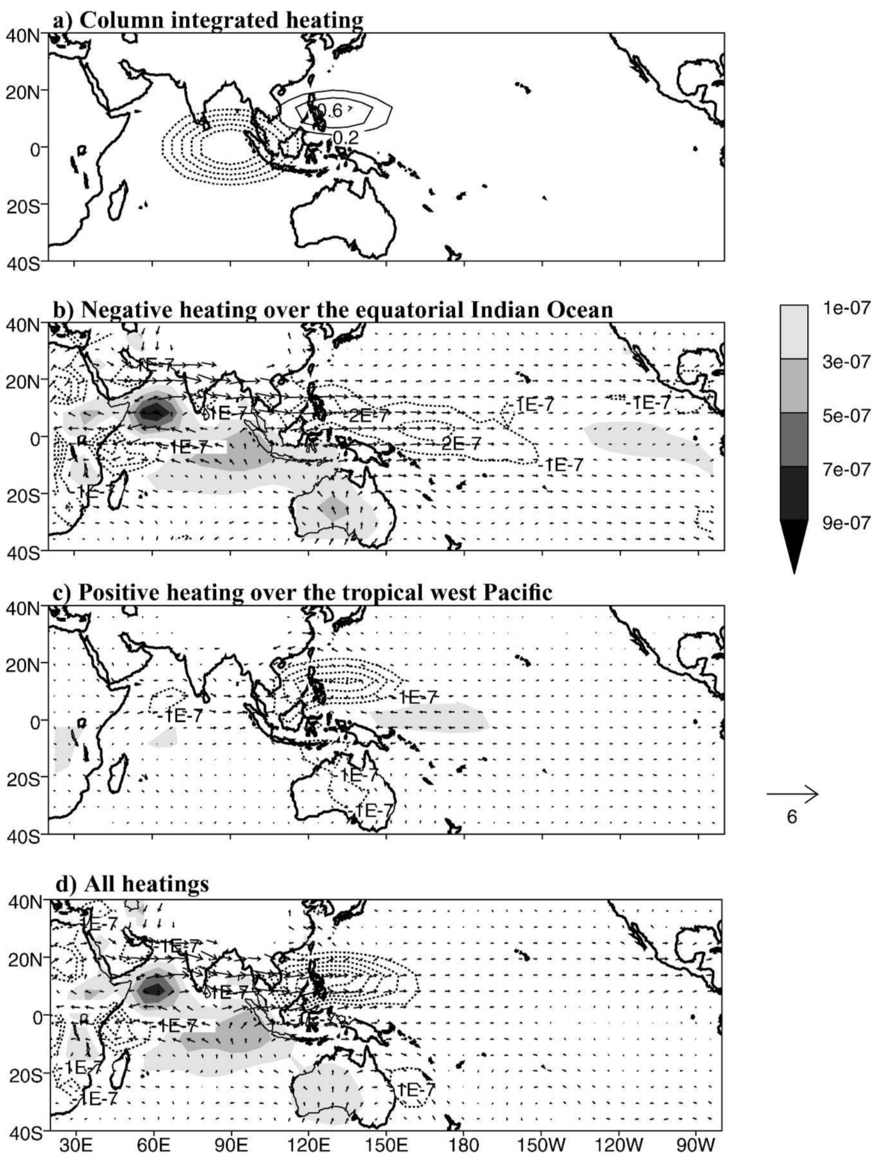


FIG. 6. Day −15 (a) column integrated heating anomalies (K day^{-1}), steady-state response of 850-hPa wind (m s^{-1}), and divergence (s^{-1}) to day −15 heating: (b) negative heating over the equatorial Indian Ocean, (c) positive heating over the tropical west Pacific, and (d) total response [sum of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

Prescribed heating

850 hPa wind / divergence

Linear model (Watanabe and Jin 2002)

Annamalai and Sperber 2005

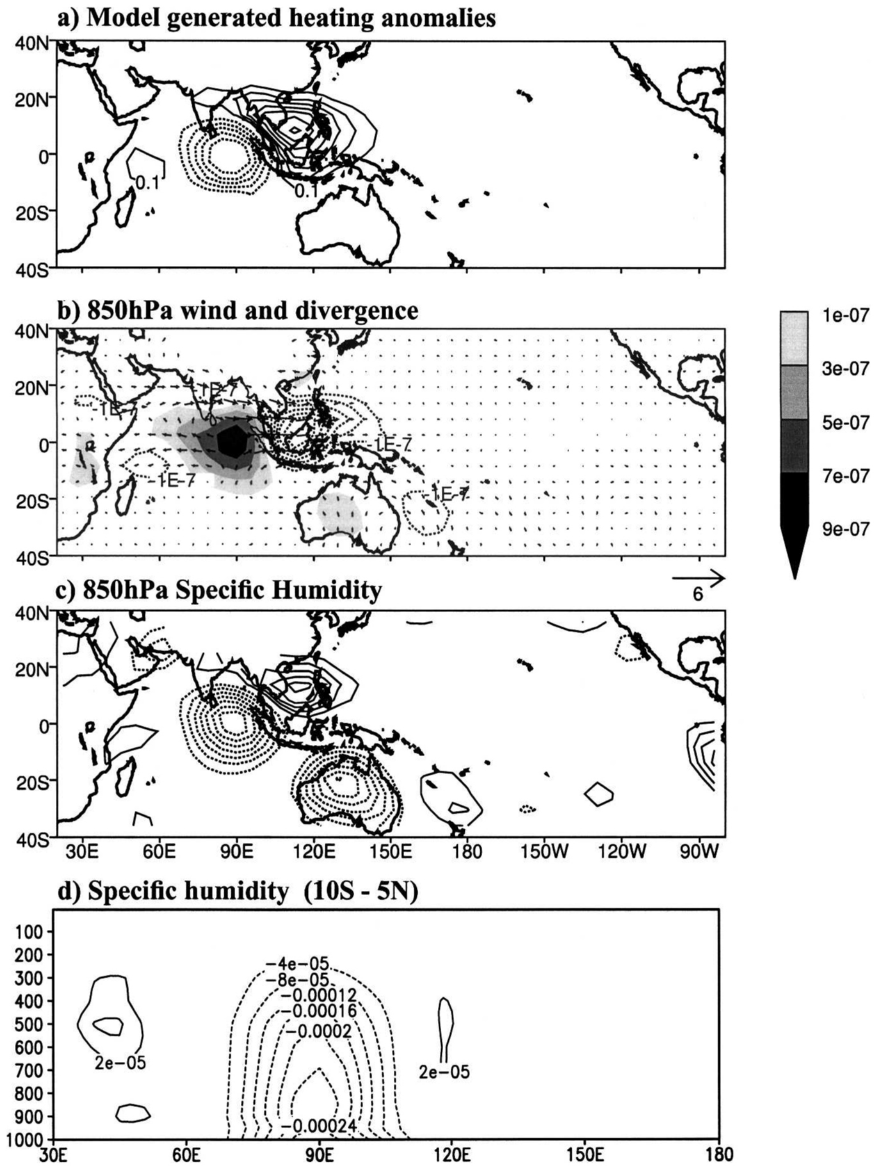
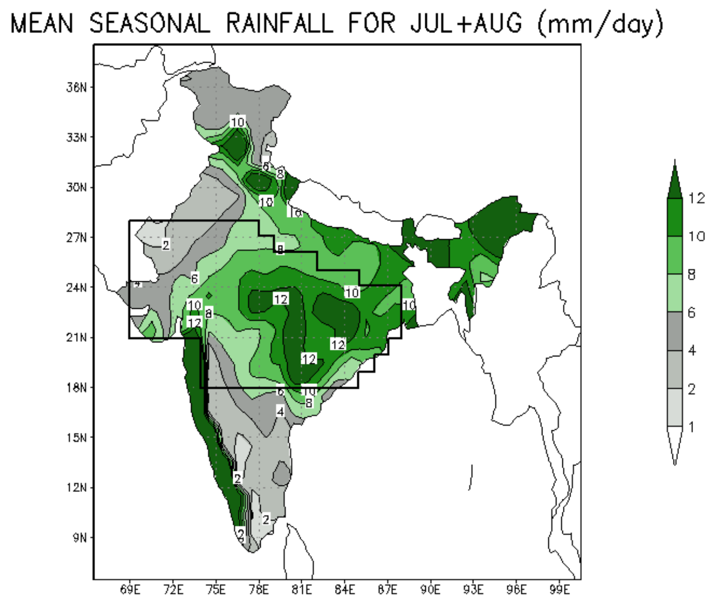
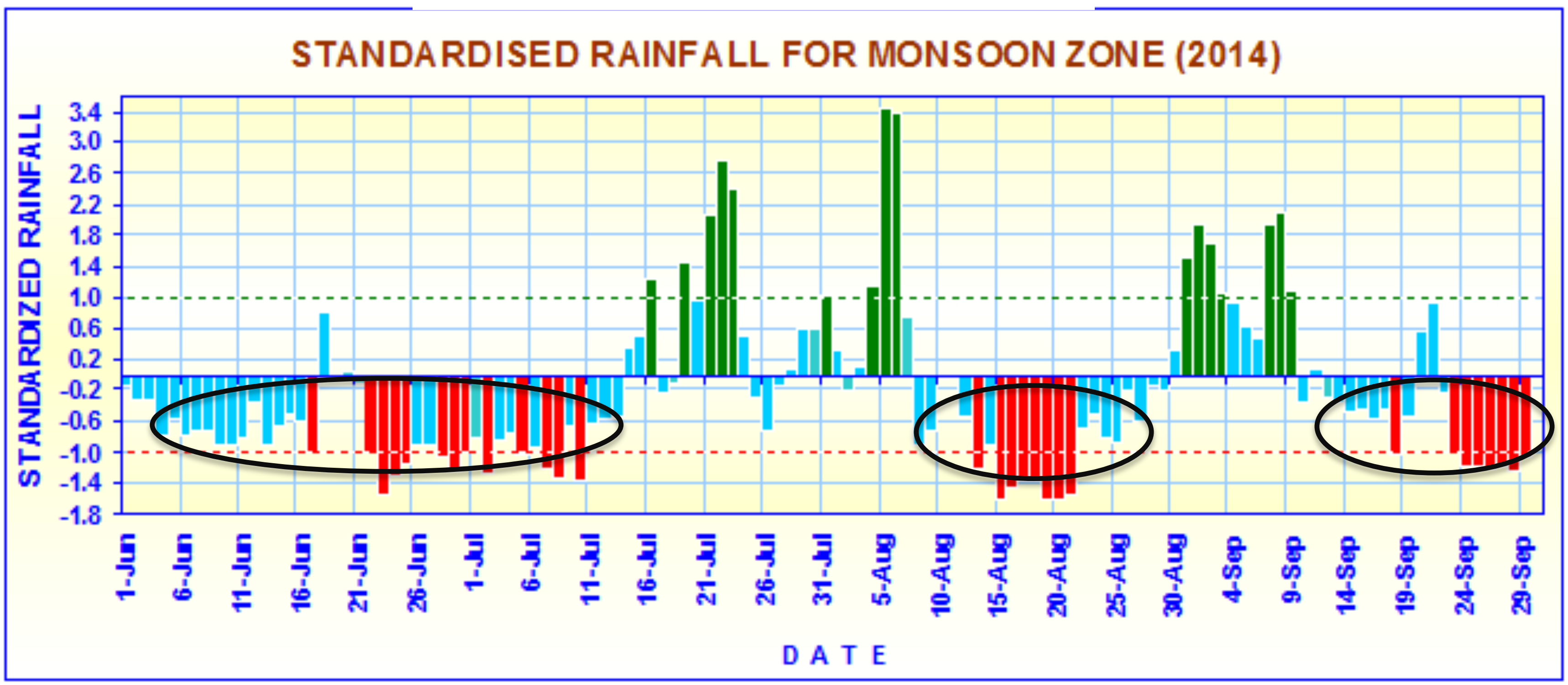


FIG. 7. (a) Model-generated heating anomalies (K day^{-1}) for prescribed cold SST anomalies over the equatorial Indian Ocean, (b) steady-state response of 850-hPa wind (m s^{-1}) and divergence (s^{-1}), (c) 850-hPa specific humidity (kg kg^{-1}), and (d) specific humidity averaged over 10°S–5°N from 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).

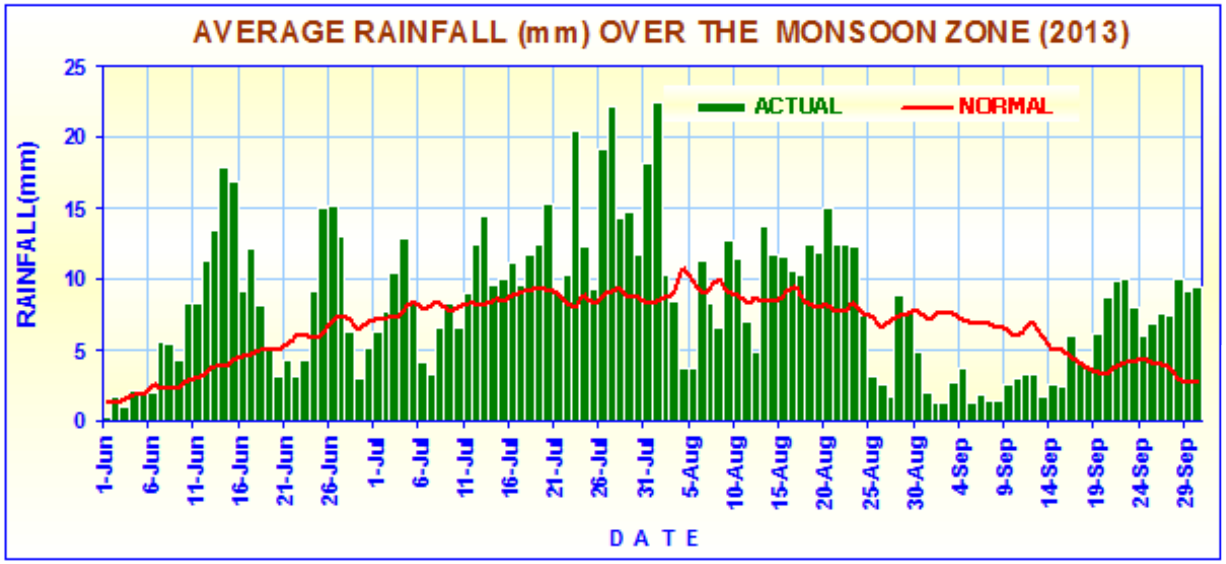
Model-generated heating

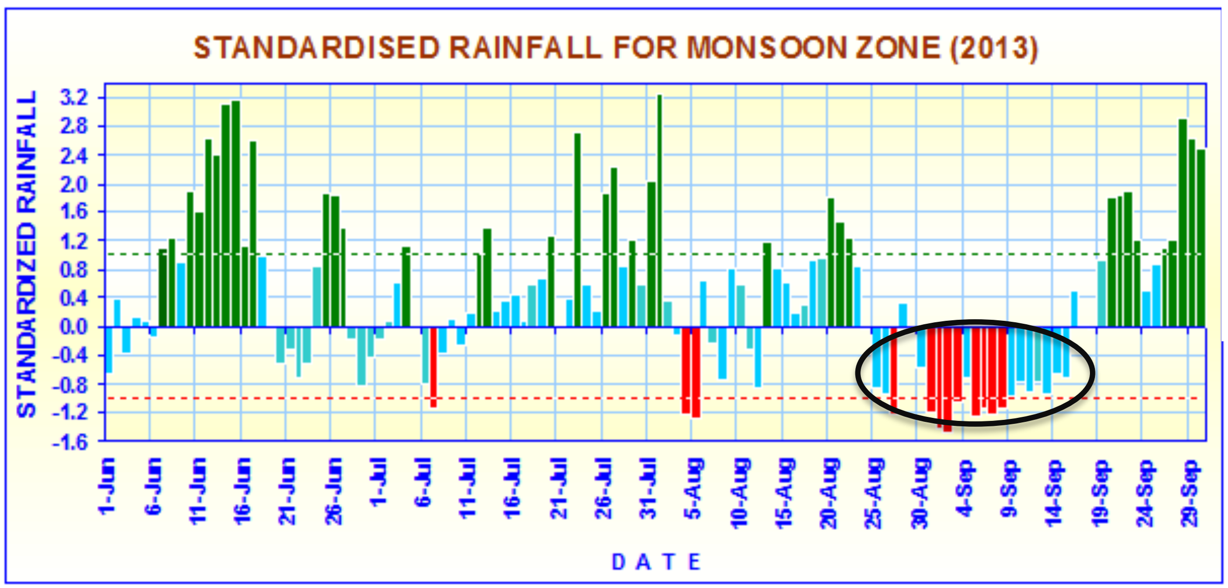
Annamalai and Sperber 2005



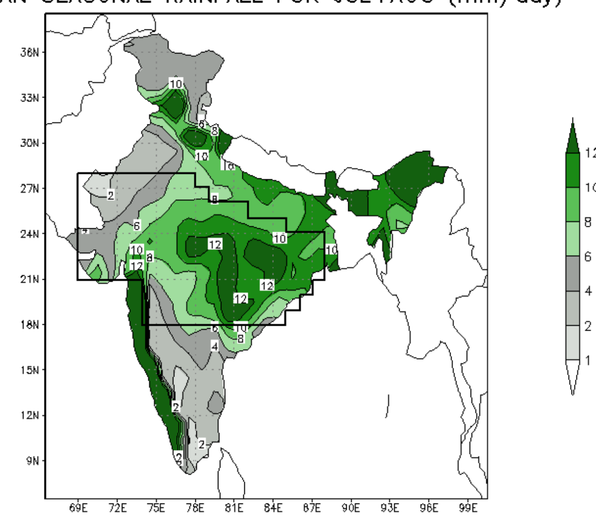


Source: India Meteorological Department, Pune

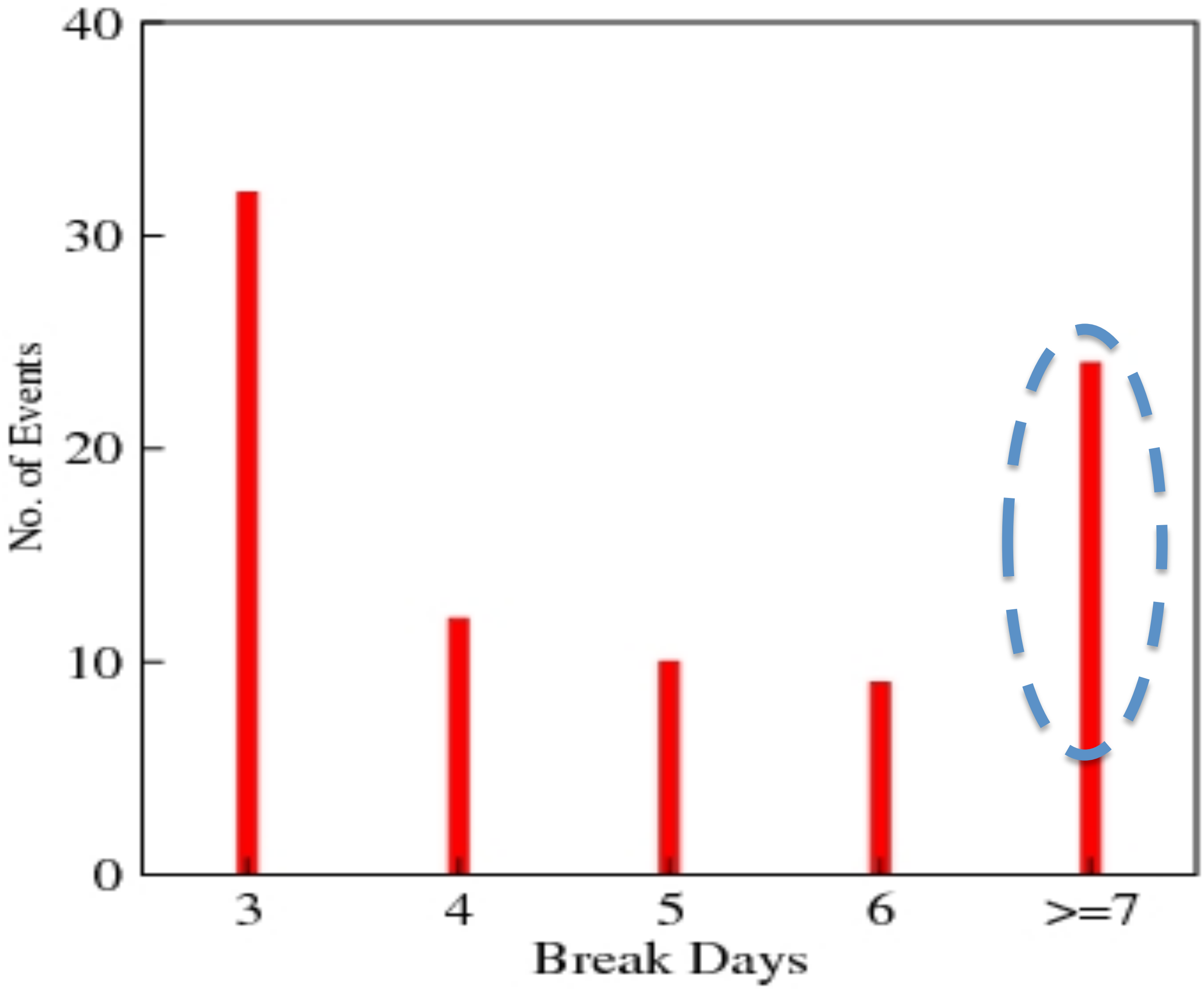




MEAN SEASONAL RAINFALL FOR JUL+AUG (mm/day)

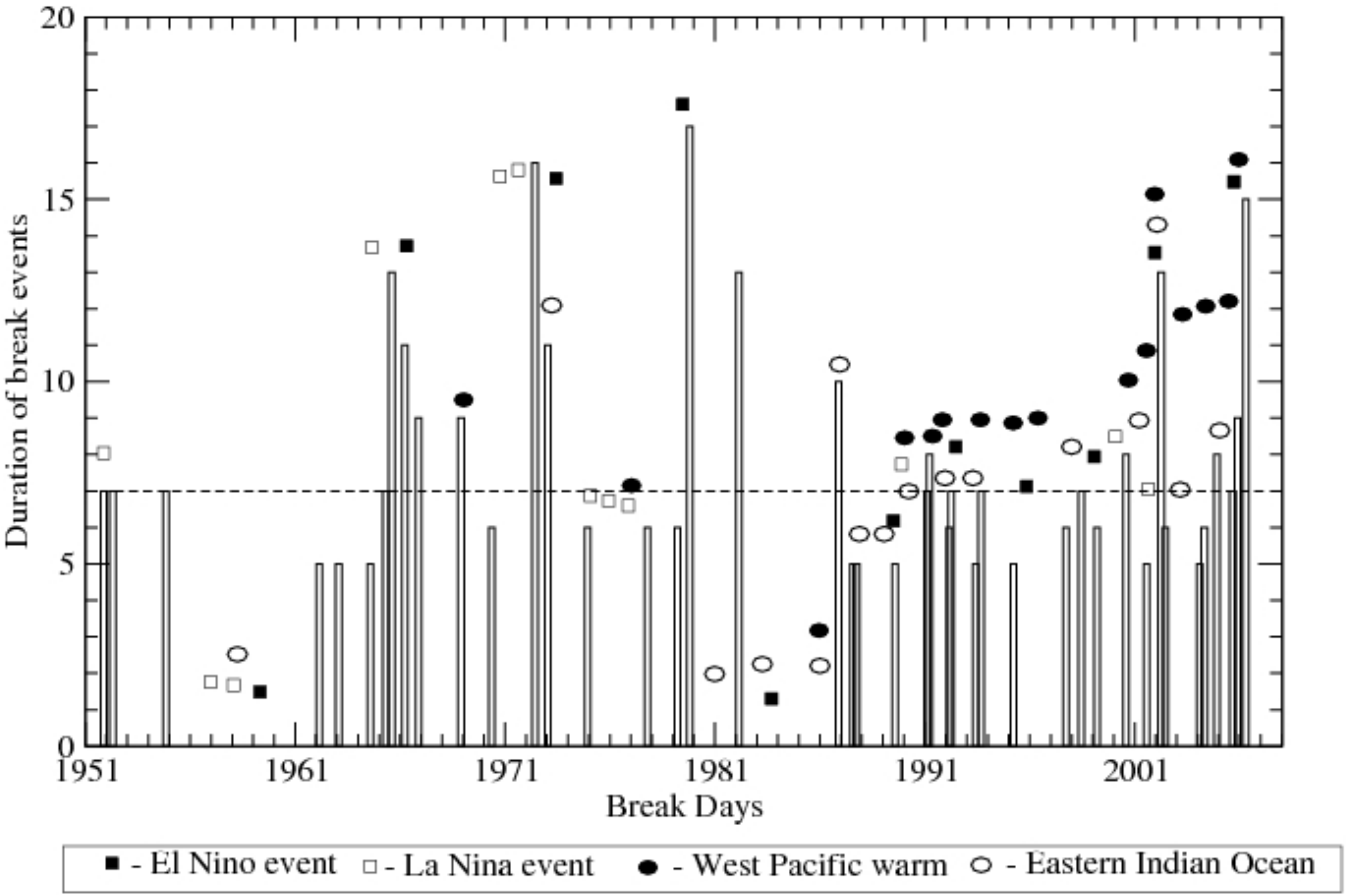


Extended monsoon breaks over central India (1951-2009)



IMD 1°x1° gridded rainfall observations

Prasanna and Annamalai (2012, JC)



Intraseasonal variability + boundary forcing

Any precursors in moist and radiative processes?

- **ERA-Interim (1989-2010) -**
- **For composite and individual cases, apply MSE budget**

Budget estimated over (i) central India

(ii) Eastern equatorial IO

(iii) Tropical western Pacific

Regional circulation anomalies forced by (ii) and (iii) are important

Representation of interaction between cumulus convection and circulation requires consideration of moisture and temperature that is represented by MSE, m, given by

$$m = C_p T + gz + Lq$$

The vertically integrated MSE tendency is approximately given by

$$\left\langle \frac{\partial m}{\partial t} \right\rangle = -\left\langle \overline{V} \bullet \nabla m \right\rangle - \left\langle \omega \frac{\partial m}{\partial p} \right\rangle + LH + SH + \left\langle LW \right\rangle + \left\langle SW \right\rangle$$

+ residuals

Charging/ discharging

Initiation/ termination

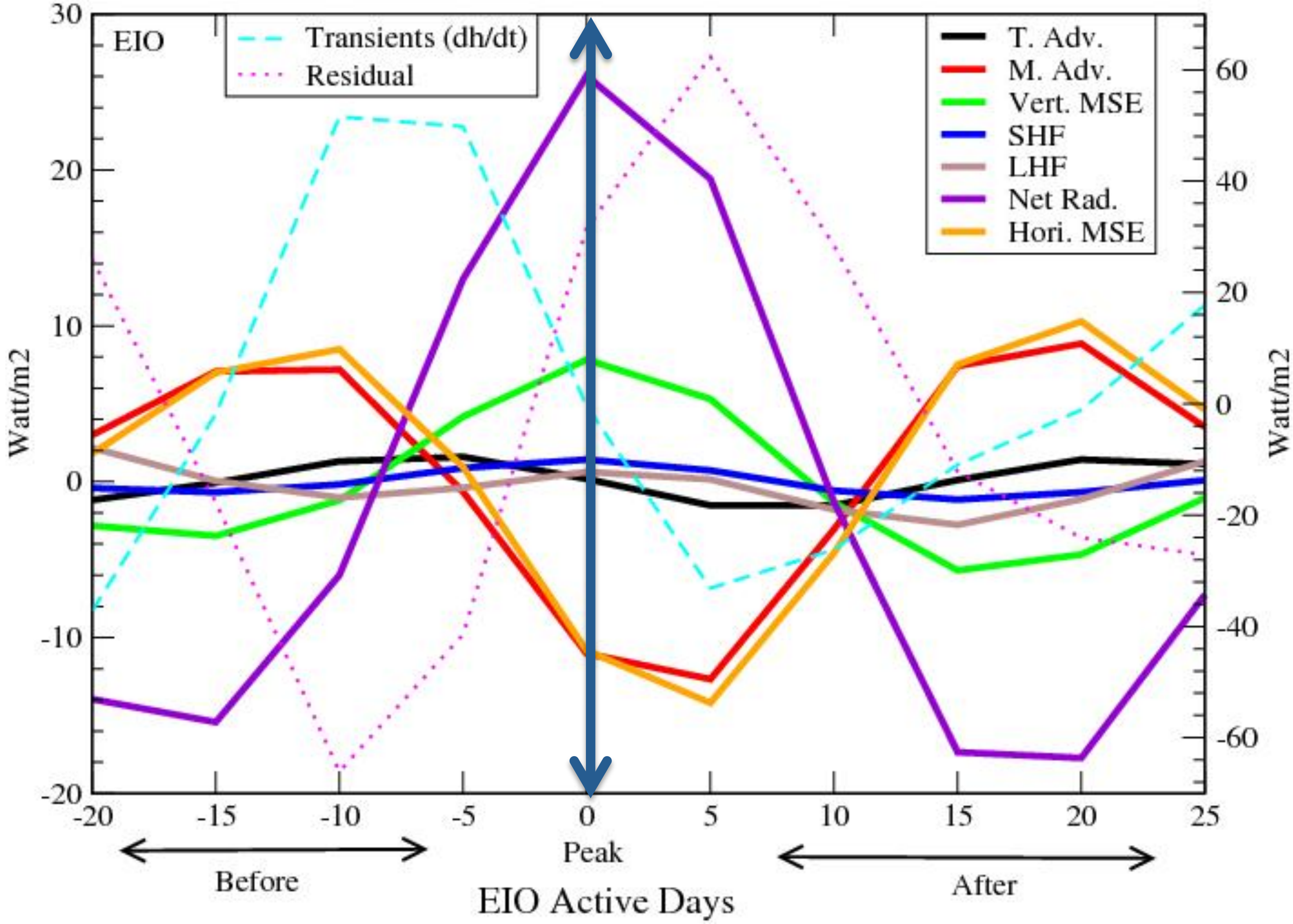
MSE export

Fluxes (negligible)

Cloud-radiative interaction (maintenance)

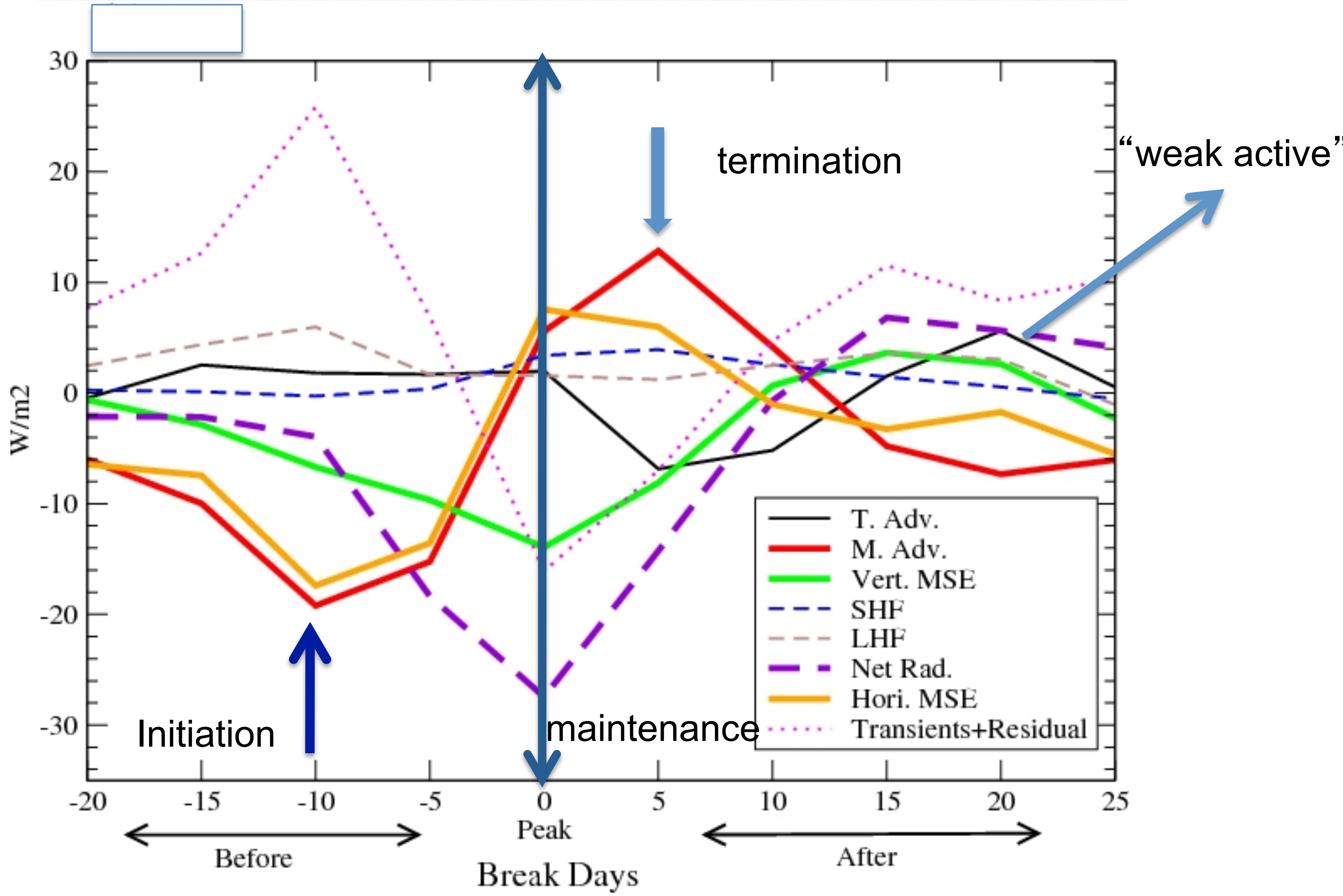
WTG approximation – temperature advection is negligible

MSE budget terms – Equatorial Indian Ocean

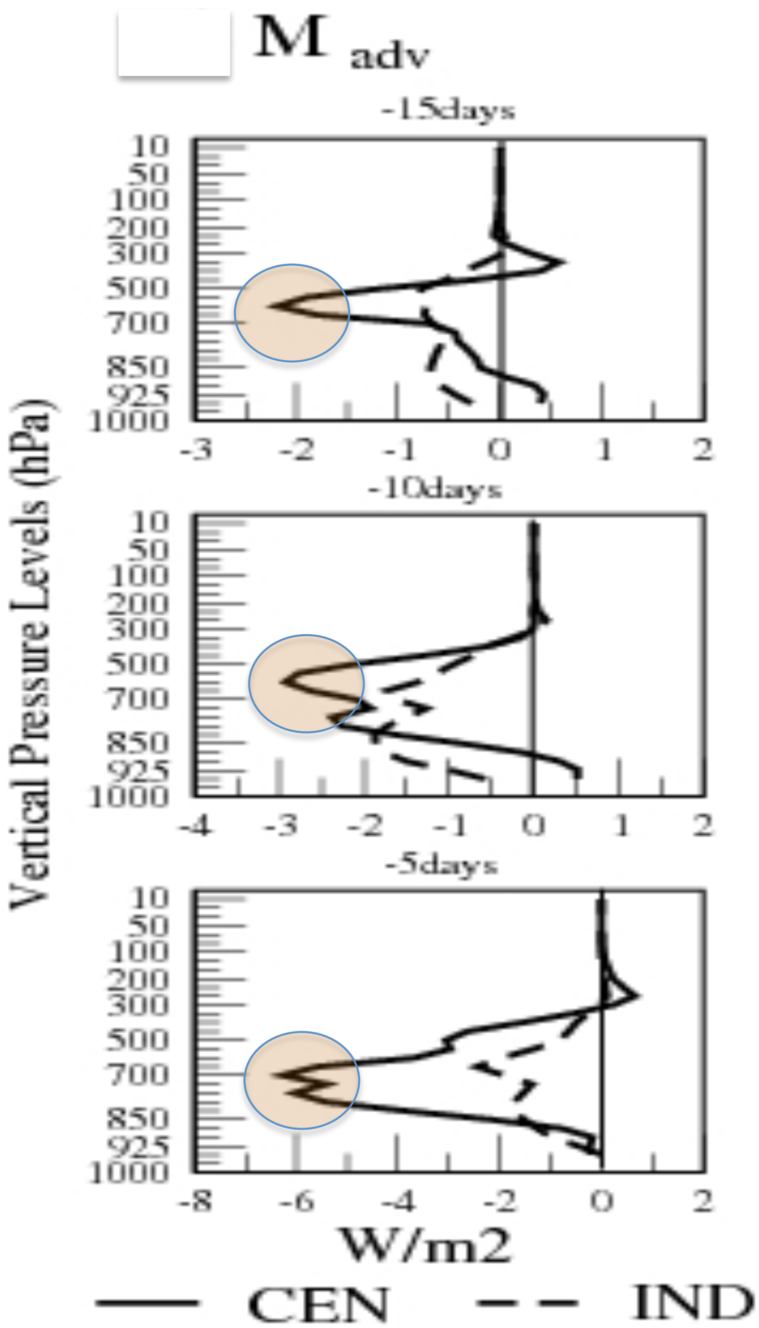


Annamalai and Prasanna (2014 – Internal processes for BSISV)

MSE budget terms – Central India (18-27N; 71-87E)



Dry adv → convection inhibition → LW cooling → descent/adiabatic warming



Dry air intrusion –

Convective inhibition layer

"deep convection sensitive to mid-troposphere moisture"

Useful predictive information

(**2002/2009 Case studies**)

Summary 1

Extended monsoon breaks

MSE budget analysis identifies

$$-\langle \overline{V} \bullet \nabla m \rangle \qquad\qquad \langle LW \rangle$$

initiation and termination — maintenance

But…….large residuals – important moist and radiative processes missing

Monsoon Mission Project – CFS*v*2

Objectives

1. To identify and quantify the processes that initiate, maintain and terminate extended monsoon episodes in multiple global reanalysis data sets and then use field observation to constrain uncertainties in the reanalysis products

2. To examine if these processes are faithfully represented in the hindcasts performed with CFSv2, and if not, to offer recommendations for model improvements

3. Based on the identified physical processes, to incorporate nudging on model equations in CFSv2 and perform a series of prediction experiments and assess their skill

Questions of interest

1. Moist and radiative processes that initiate and maintain extended monsoon episodes?
   Identify robust precursors – lack of obs – model prejudices – parameterizations

2. Does WTG approximation valid over central India?

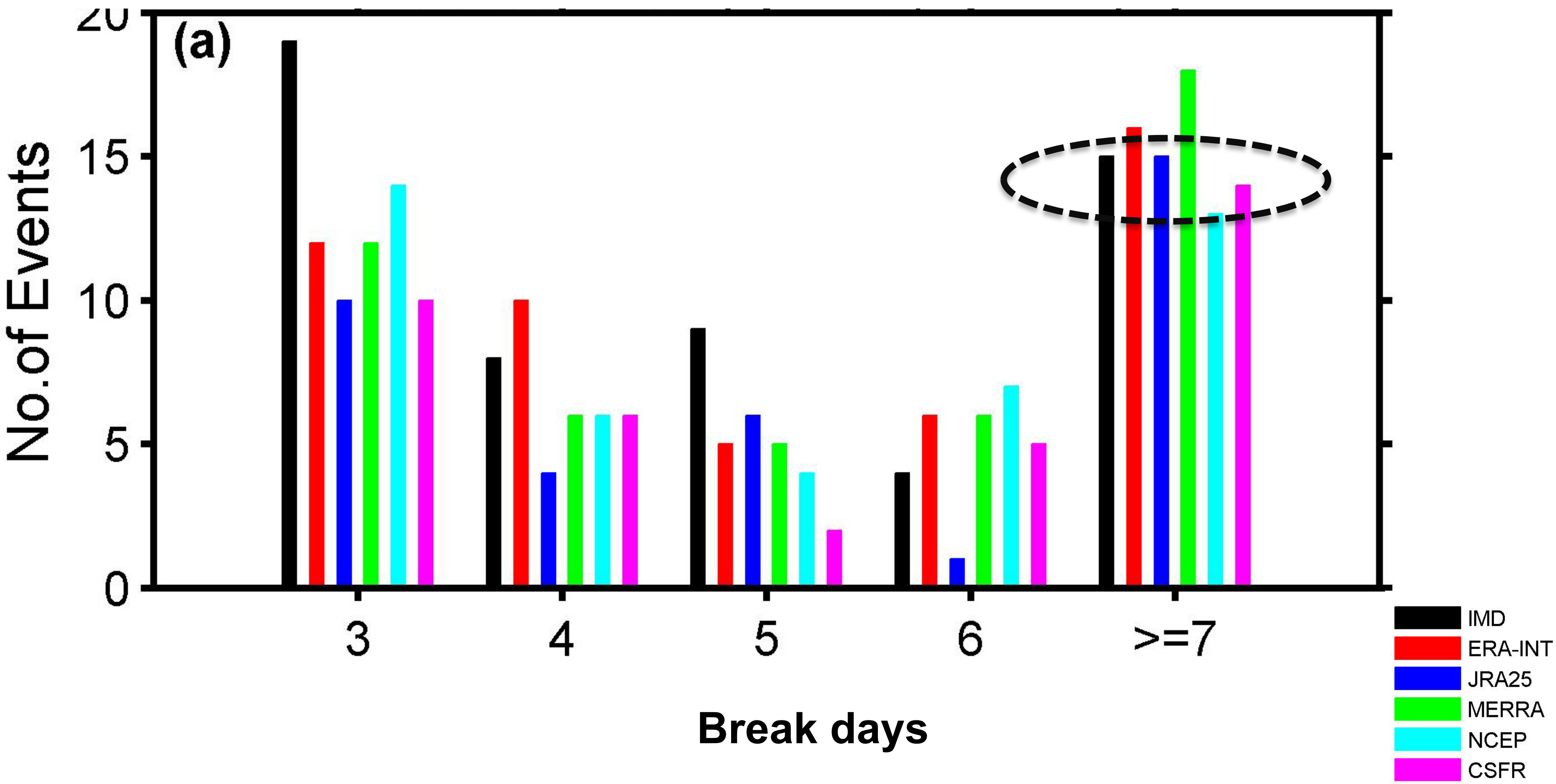
3. Do the identified mechanism(s) explain the observed extended breaks during 2014?

Direct implication

Physically-based diagnostics – model improvement (CFSR – limitations)

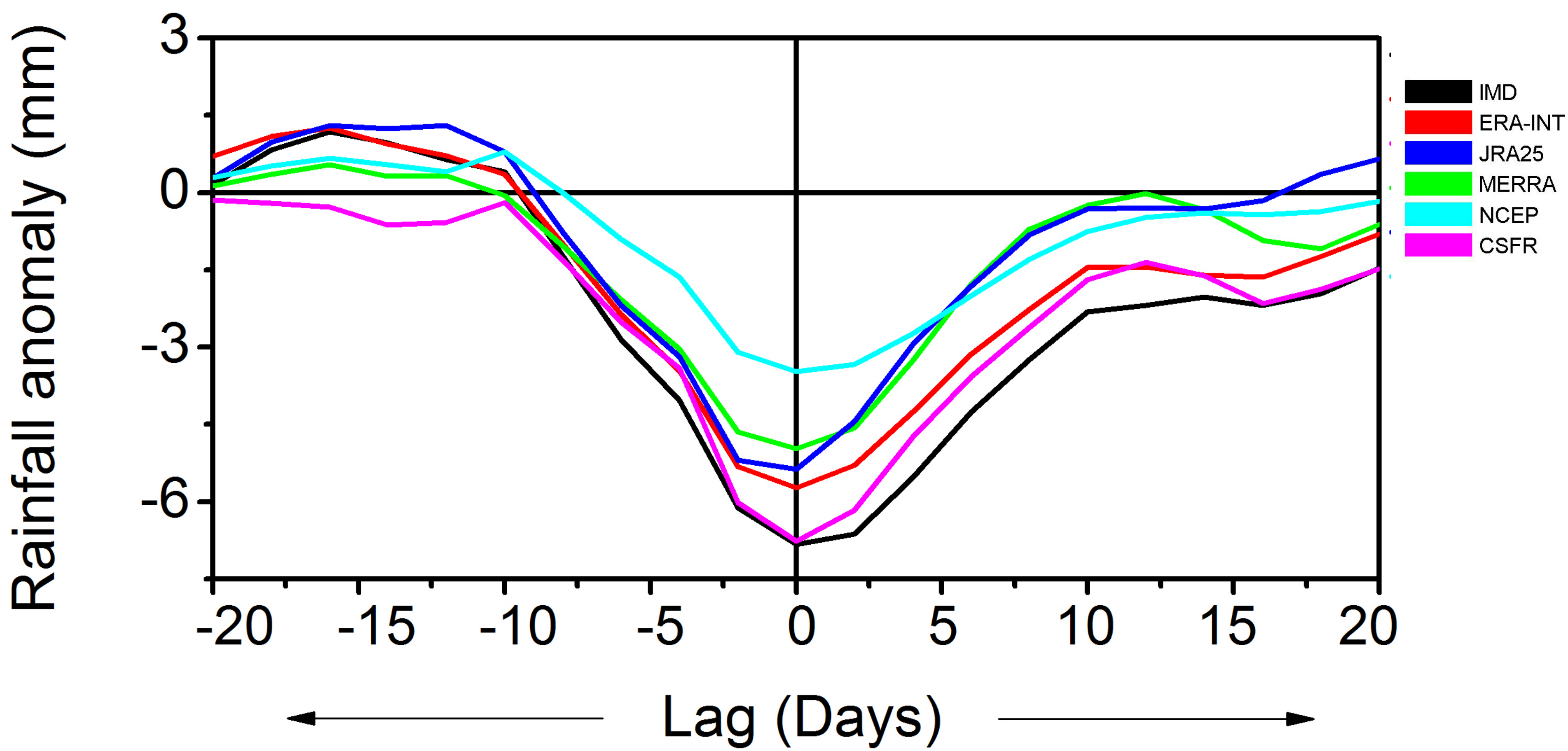
Need for high-quality direct field observations (**ARM-type**) to constrain model physics

Histogram of break days over Central India (21-27°N, 72-85°E)



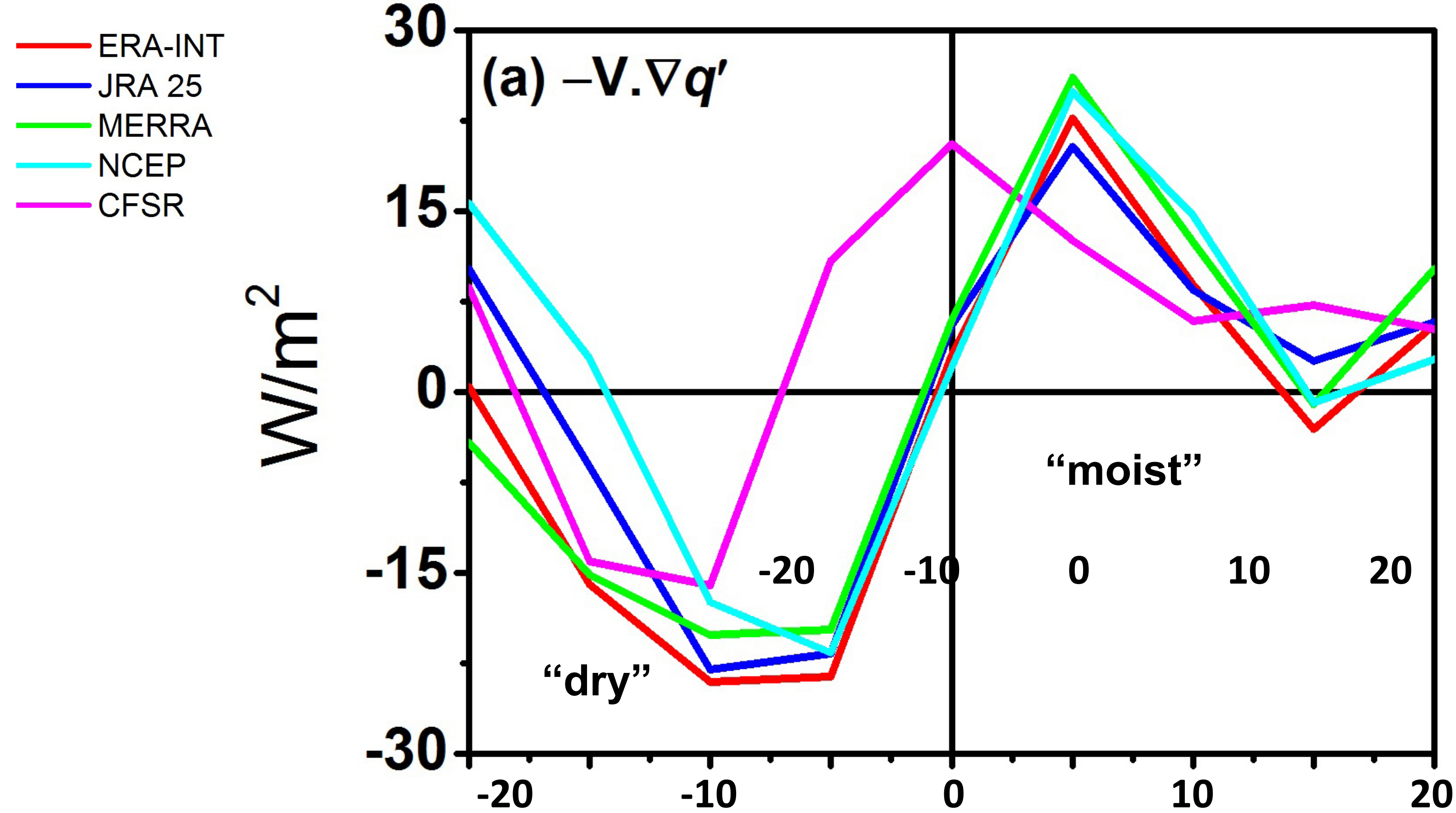
Extended breaks arise as a superposition of BSISV and boundary forcing (SST)

Composite precipitation evolution during extended breaks over central India



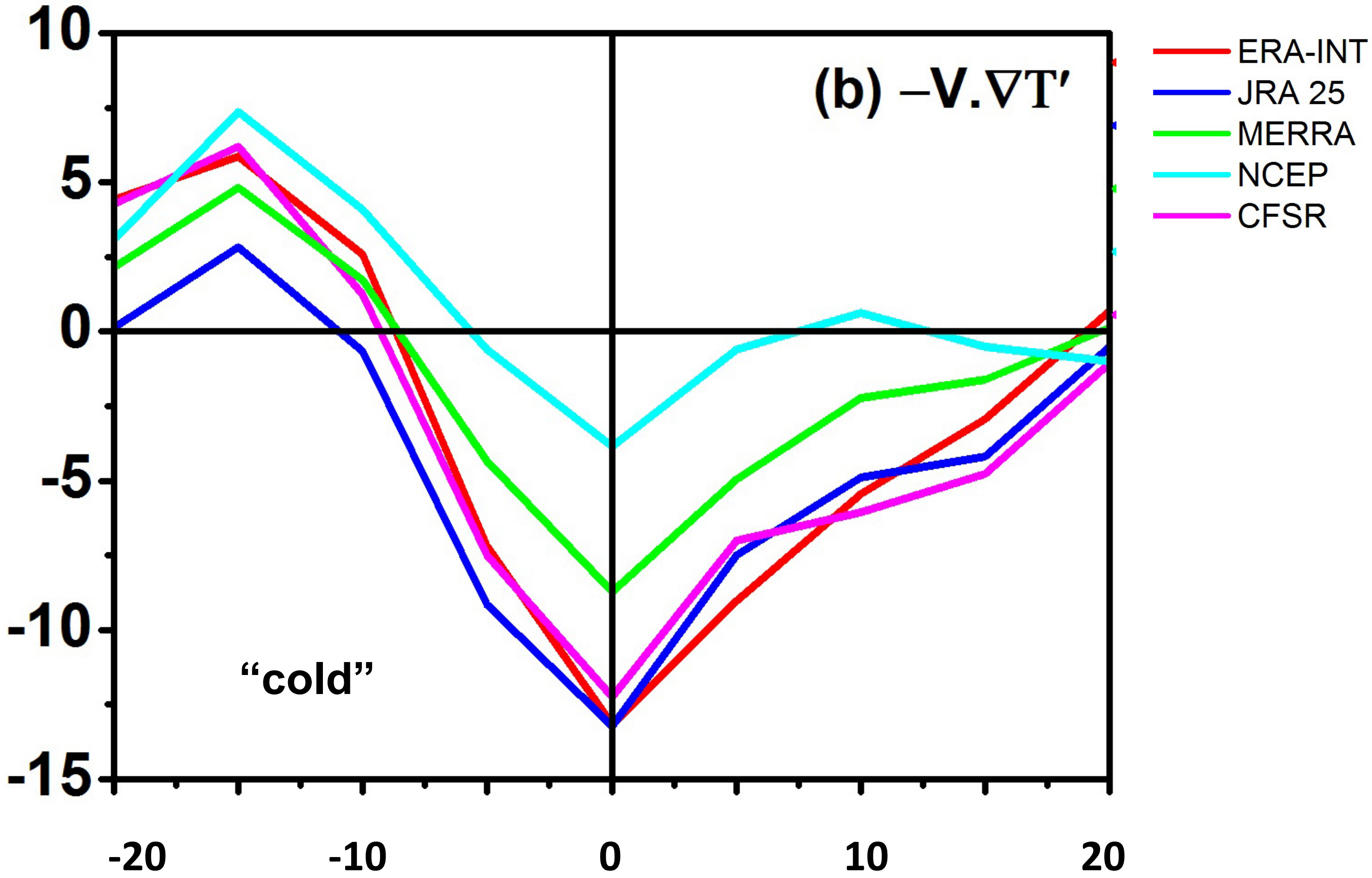
Are CFSR rainfall variations due to correct reasons?

Horizontal advection of moisture



"horizontal advection of dry air leads peak break by about 10-12 days
except in CFSR where the lead is about 15 days"

Horizontal advection of temperature

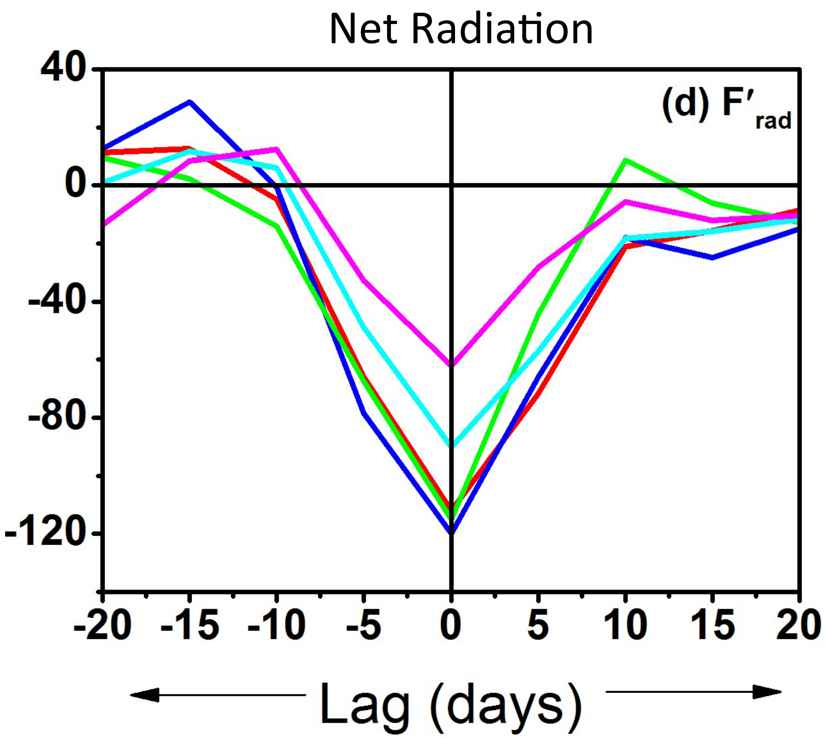


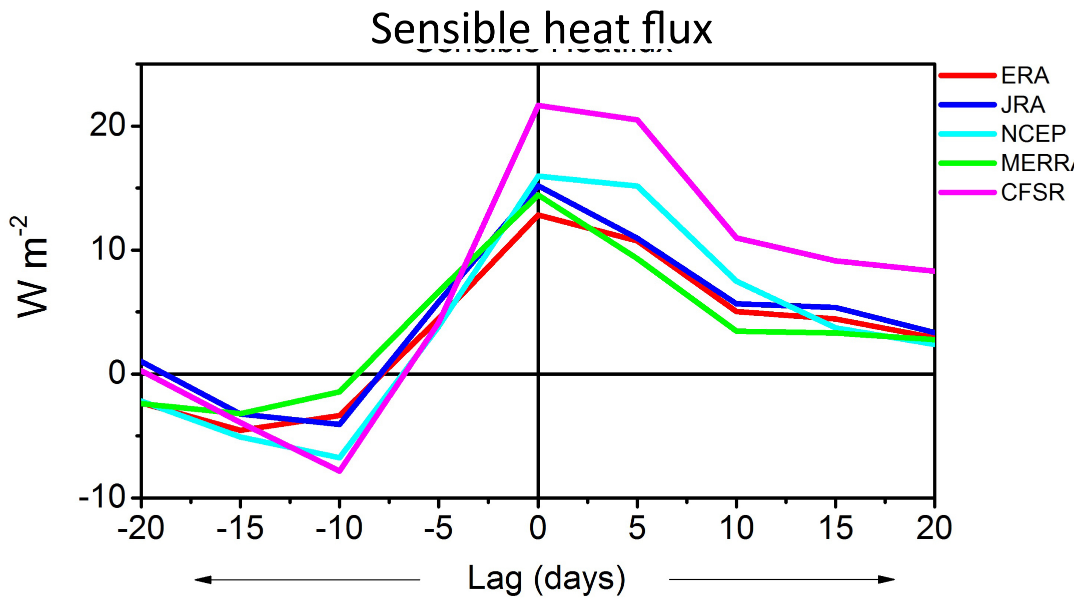
"horizontal advection of temperature contributes to about 50% to that of moisture but is "in-phase" with the rainfall anomalies"

Weak Temperature Gradient (WTG) approximation?

Annamalai and Mohan (2016)

Diabatic terms



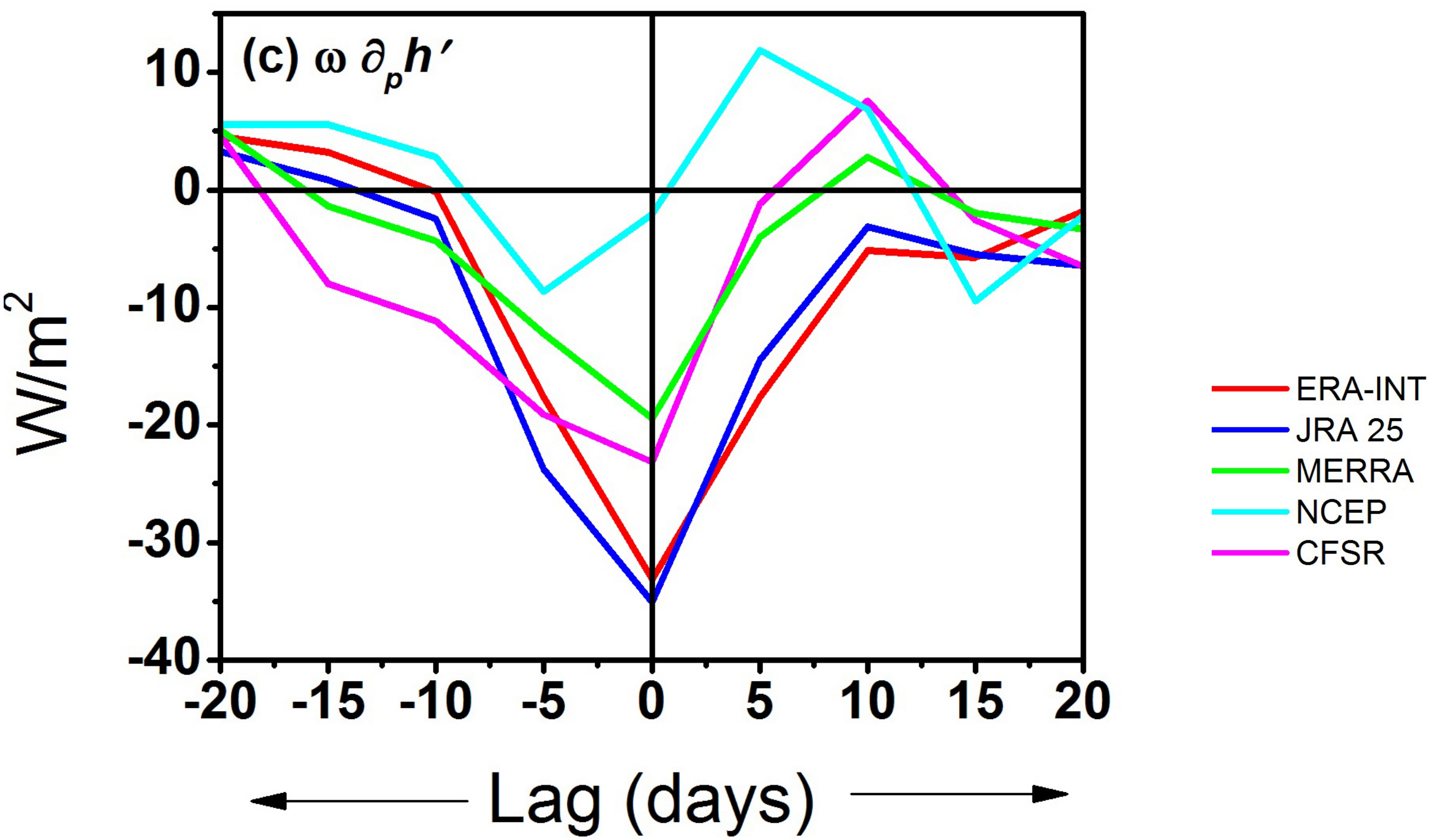


$$F_{rad} = S_t^{\downarrow} - S_t^{\uparrow} - S_s^{\downarrow} + S_s^{\uparrow} - R_t^{\uparrow} - R_s^{\downarrow} + R_s^{\uparrow}$$

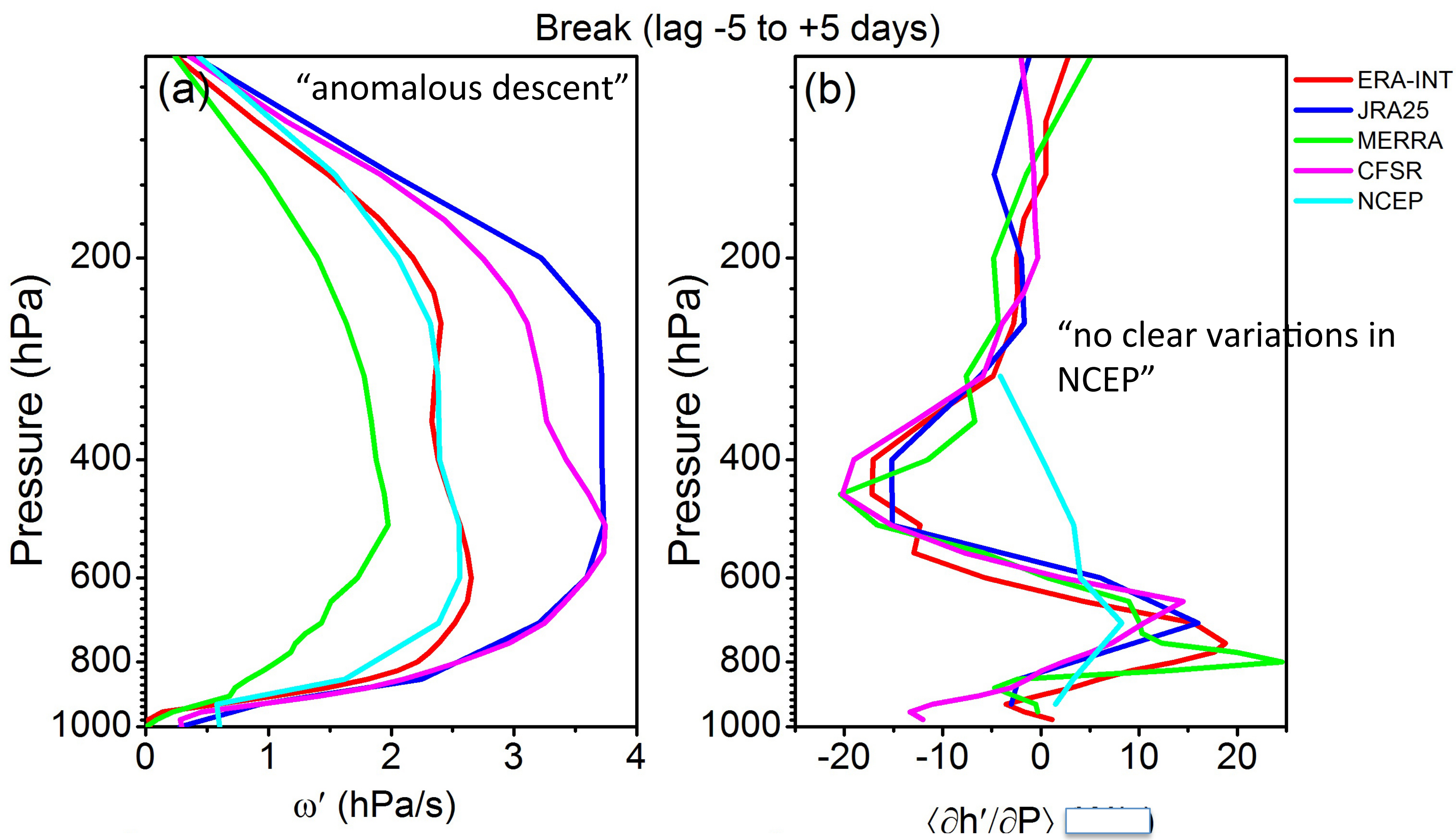
CFSR – weak (strong) cloud-radiative (surface instability)

Dry/cold adv → convection inhibition → LW cooling → descent/adiabatic warming

Vertical advection of MSE (export of MSE)



a measure of convective forcing



Gross moist stability (GMS): positive entropy gradient at low-levels and omega is positive – GMS is positive - exports MSE (DSE) –

: negative entropy gradient at mid-high levels and omega positive – GMS is negative – imports low MSE – convective inhibition

Large uncertainties in vertical velocity – depends on convective parameterizations employed

Summary 2

MSE budget analysis identifies

$$-\left\langle \overline{V} \bullet \nabla m \right\rangle$$

initiation and termination

$$-\left\langle \overline{V} \bullet \nabla T \right\rangle \quad \left\langle LW \right\rangle$$

maintenance

Identified mechanisms - Robustness across all reanalysis – encouraging

large uncertainties in vertical structure of vertical velocity

Full details including that of extended active monsoon phases, monsoon revival will be in…

Mohan and Annamalai (2016, submitted)