Multi-Scale Climate Processes and Rainfall Variability in the Maritime Continent

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Outline

- **Part 1: Maritime Continent climate: Why precipitation is concentrated over islands**

- **Part 2: Multi-Scale Climate Processes associated with the Annual Cycle of Monsoon, ENSO, Daily Weather Types and Diurnal Cycle: e.g., ENSO related dipolar patterns of rain anomalies over Java Island & Borneo Island**

Multi-scale climate processes
(spatially and temporally)

ENSO (year-to-year)

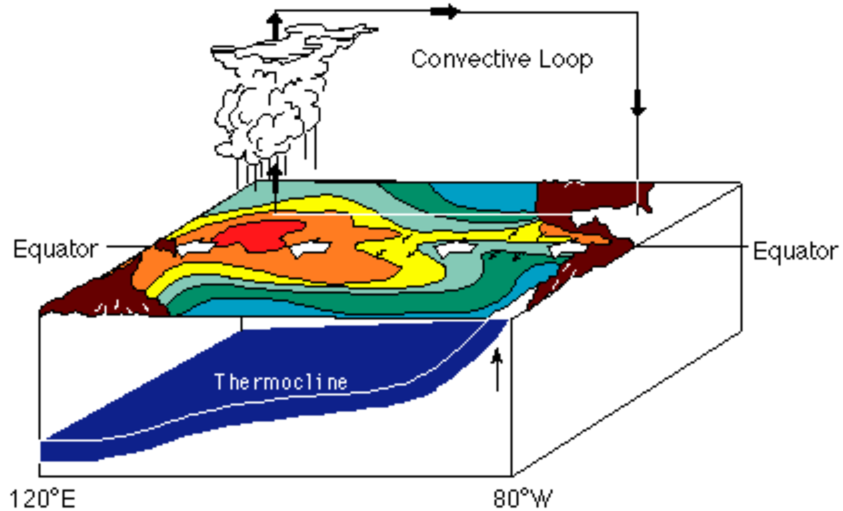
Monsoon (seasonal)

MJO (sub-seasonal)

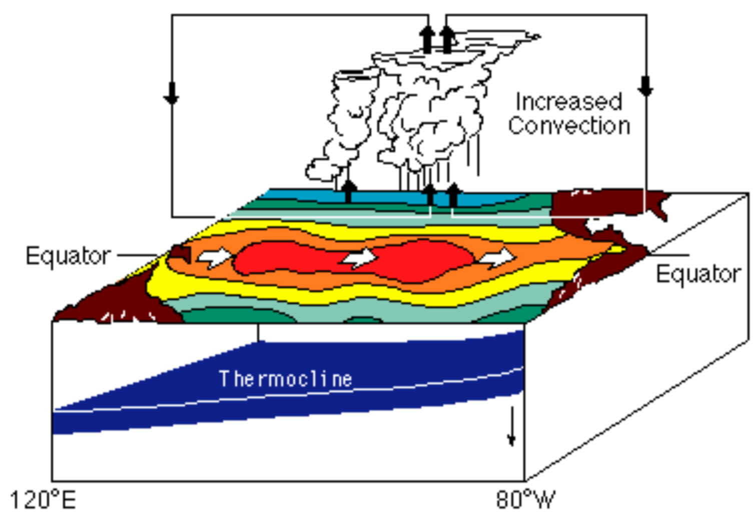
Diurnal Cycle (24-hourly)

http://www.pmel.noaa.gov/toga-tao/pmel-graphics/web-graphics.html

Normal Conditions



El Niño Conditions



Weather Types (WTs) and Climate Variability over the Maritime Continent

Processes:

- Monsoon
- ENSO
- MJO
- Daily WT
- Diurnal Cycle (sea-breezes)

Multi-Scale Process Study by Using Synoptic Daily WTs:

1. Monsoonal Damping Effect on the Diurnal Cycle (Qian 2008; Qian et al. 2010)
2. Wake Effect on the Diurnal Cycle (Qian et al. 2013)
3. MJO and ENSO Impacts on WTs (Moron et al. 2015)

Part 1: Why precipitation is concentrated over islands in the Maritime Continent?

CMORPH satellite observation (.25 x .25 degree): Rainfall is mostly concentrated over the islands in the Maritime Continent. Why?

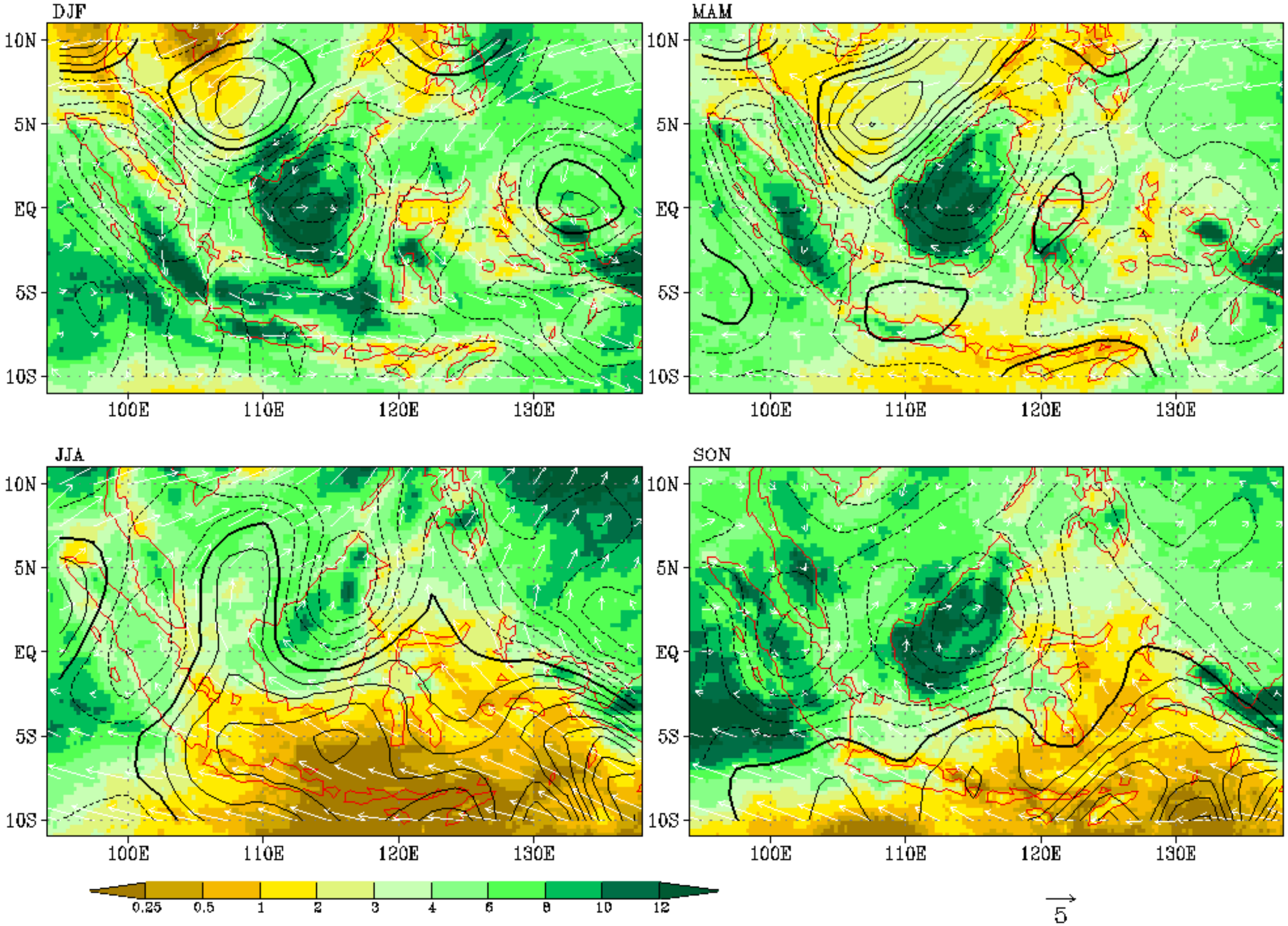


Fig.2 The averaged (2003-2005) CMORPH seasonal precipitation (mm/day, shaded), and the climatology (1971-2000) of the NNRP horizontal winds (vector) and divergence (contour) at 925 hPa in the Maritime Continent.

Satellite observation: diurnal cycle of 3-hourly rain rate

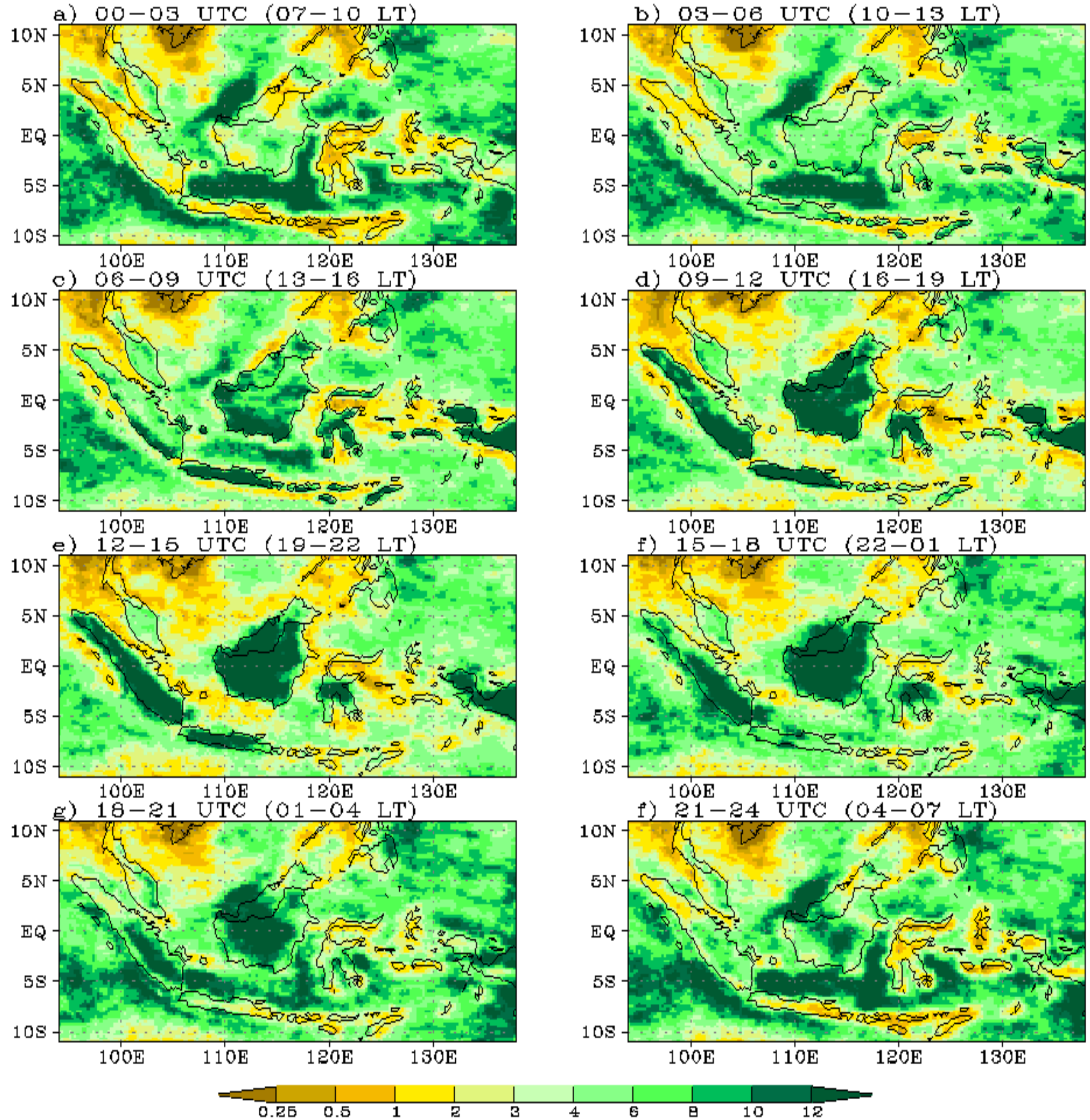
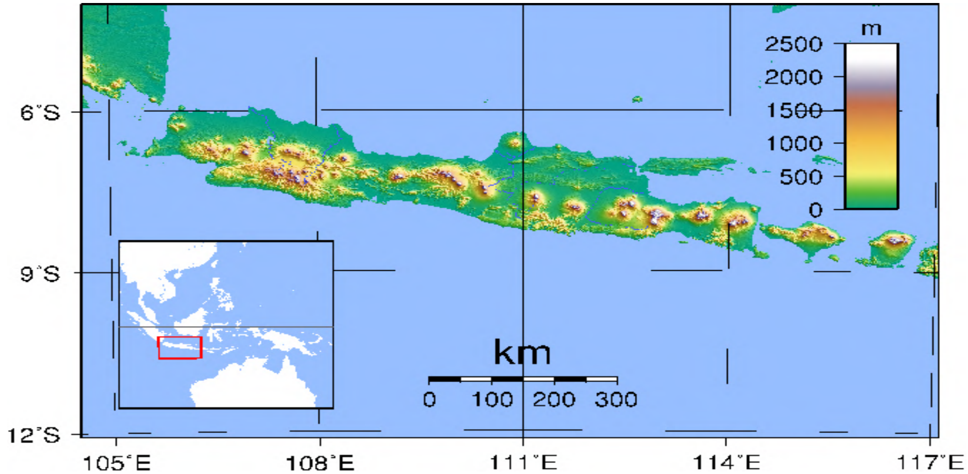


Fig.3 Diurnal cycle of CMORPH precipitation (mm/day) in DJF in the Maritime Continent. The local standard time is denoted by LT, which is seven hours ahead of the UTC.

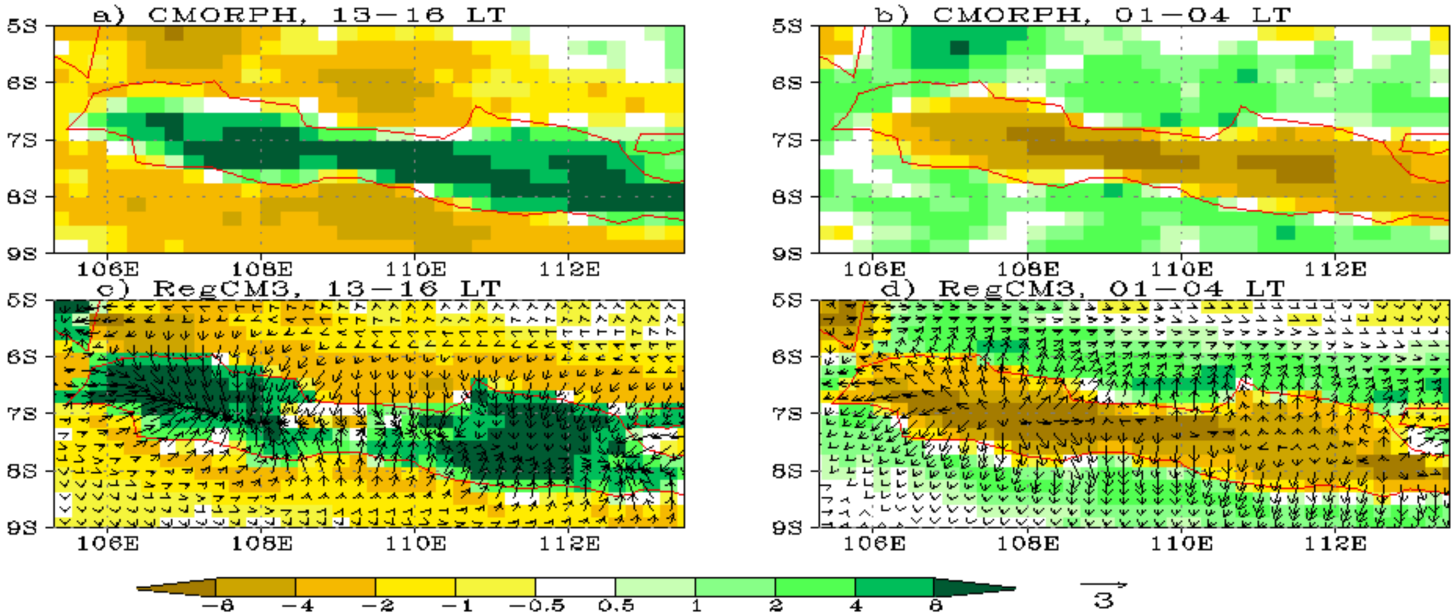
Java

Indonesia



Sea breezes (pm)

Land breezes (am)



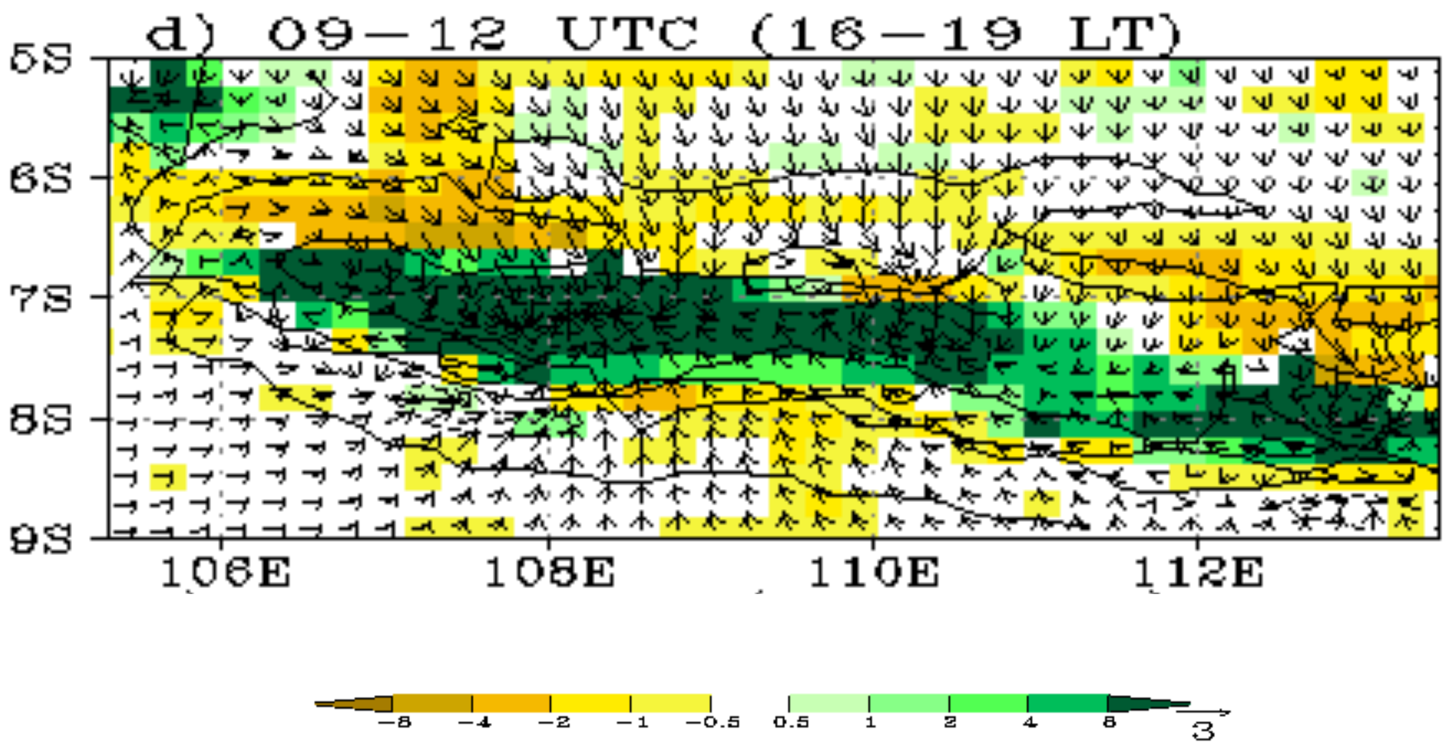
Observ.

RegCM3

Diurnal cycle of rainfall over Java Indonesia associated with land–sea breezes, shown by the CMORPH satellite estimated rainfall in day (a) and night (b), and the RegCM3 regional climate model simulated rainfall (mm/day, shaded) and surface winds (m/s, vector) in day (c) and night (d), in the wet season of December to February. "LT" denotes local standard time in Jakarta, Indonesia. Daily means are substracted to highlight diurnal cycles. Coastlines are red.

Effect of **mountain-valley breezes** on the diurnal cycle of rainfall over Java

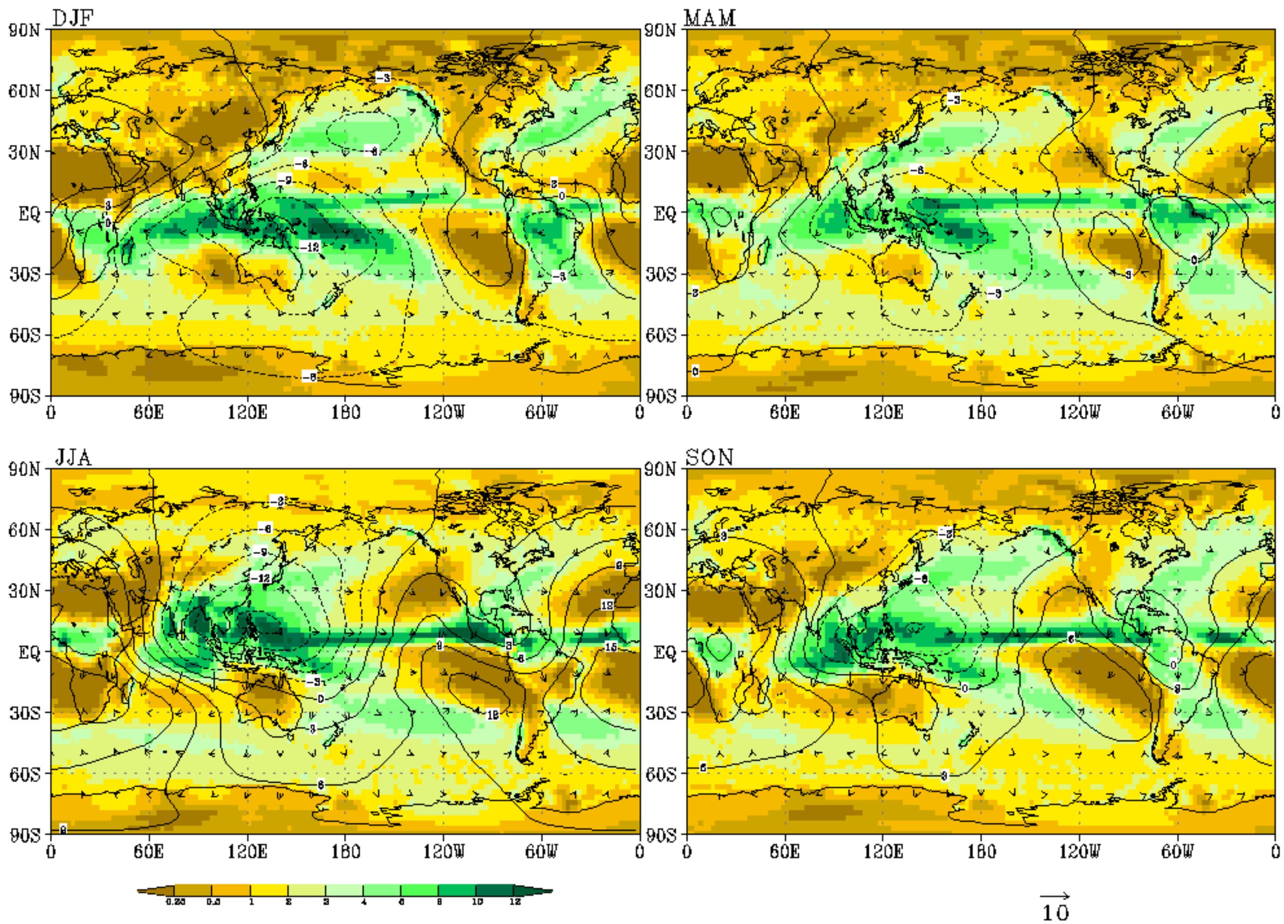
(RegCM3 control run – flat island run)



GCM Implication

Observed global precipitation & 200hPa velocity potential

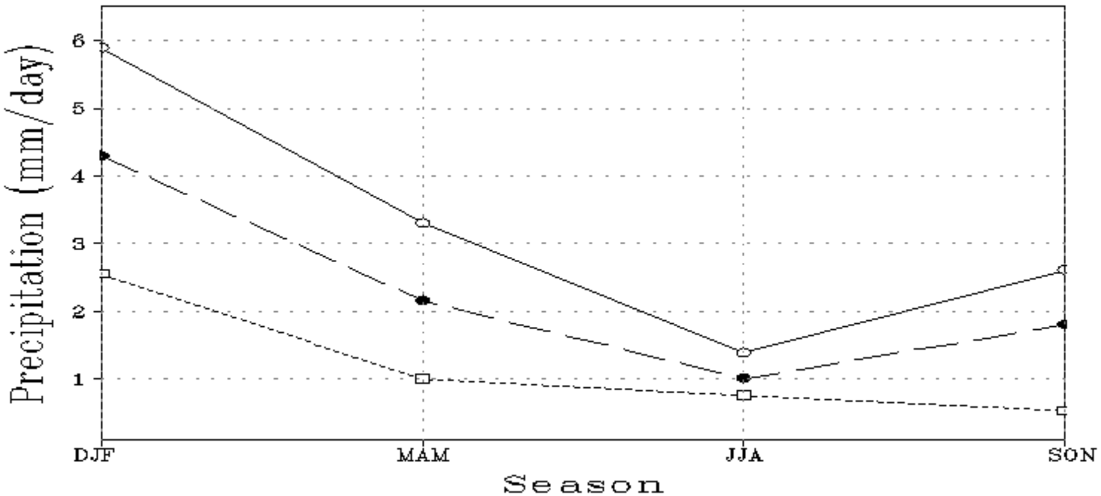
The eastern Indian/western Pacific warm pool and the Maritime Continent is the largest rainy region over the world – a "**boiler box**" for large-scale atmospheric circulation



Climatology (1982–2002) of CMAP Seasonal Precipitation (mm/day; shaded), and NNRP Velocity Potential (contour,1e6) and Divergent Wind (vector) at 200hPa

Global Implication

Regional model results: Underestimation of terrain and islands results in underestimation of precipitation



solid: island with mountain

long dash: flat island

Short dash: no island

Question: What if islands and terrain in SE Asia are under-represented in GCMs?

Systematic Errors: **Under-representation of topography in coarse-grid global models systematically under-estimates rainfall in the Maritime Continent and then causes errors in the atmospheric general circulation**

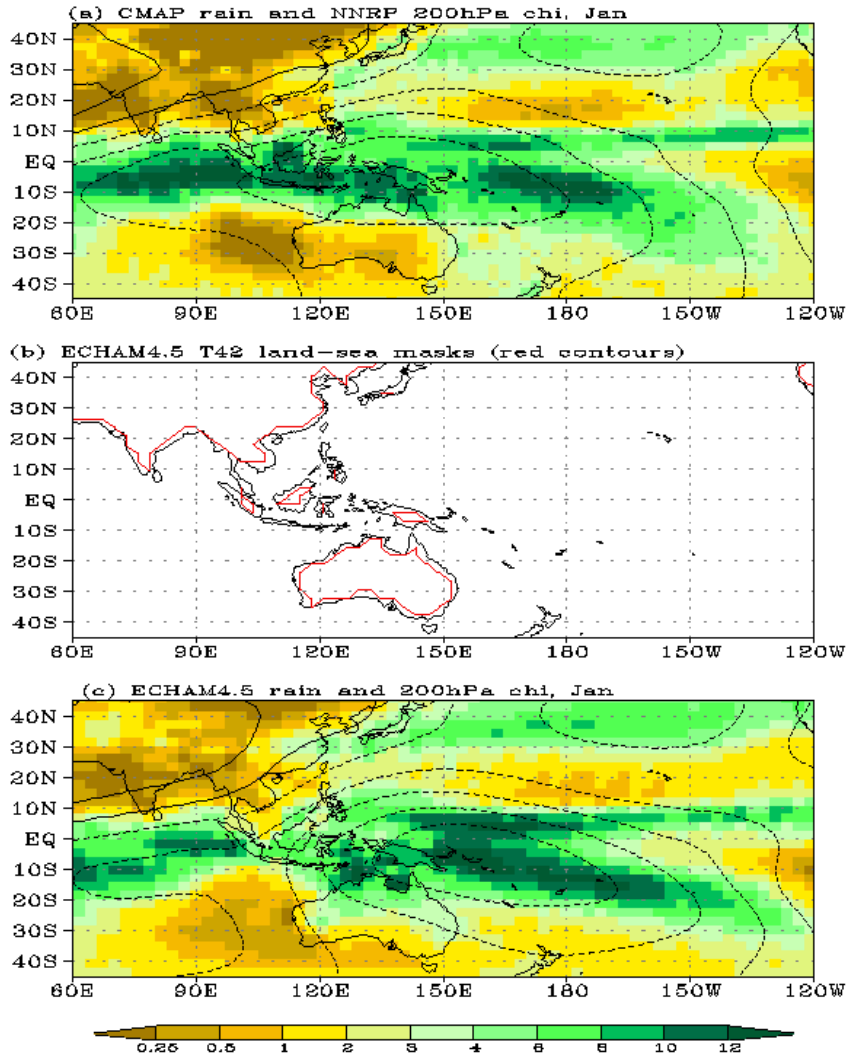


Fig.10 (a) Climatology (1982–2002) of the observed CMAP monthly precipitation (mm/day, shaded), and the NNRP 200hPa velocity potential (contour, interval 1e6) in January. (b) Land-sea masks in ECHAM4.5 T42 model (red contours). (c) Climatology (1982–2002) of the simulated ECHAM4.5 precipitation (mm/day, shaded), and the 200hPa velocity potential (contour).

Summary of Part 1

Rainfall is concentrated over islands

because of

(a) Sea breeze convergence

(b) Mountain-valley breeze, and

(c) cumulus merger in the sea breeze convergence zone

That also explains why more rainfall is over mountainous regions.

Global, regional and local implications

(Qian 2008 J. Atmos. Sci.)

Part 2: Multi-scale Interaction

2a. Java Island

A local dipolar structure of precipitation anomaly over Java Island associated with El Nino

Large scale climatology and ENSO impact on rainfall

ITCZ in the north in SON

ITCZ over Java in DJF

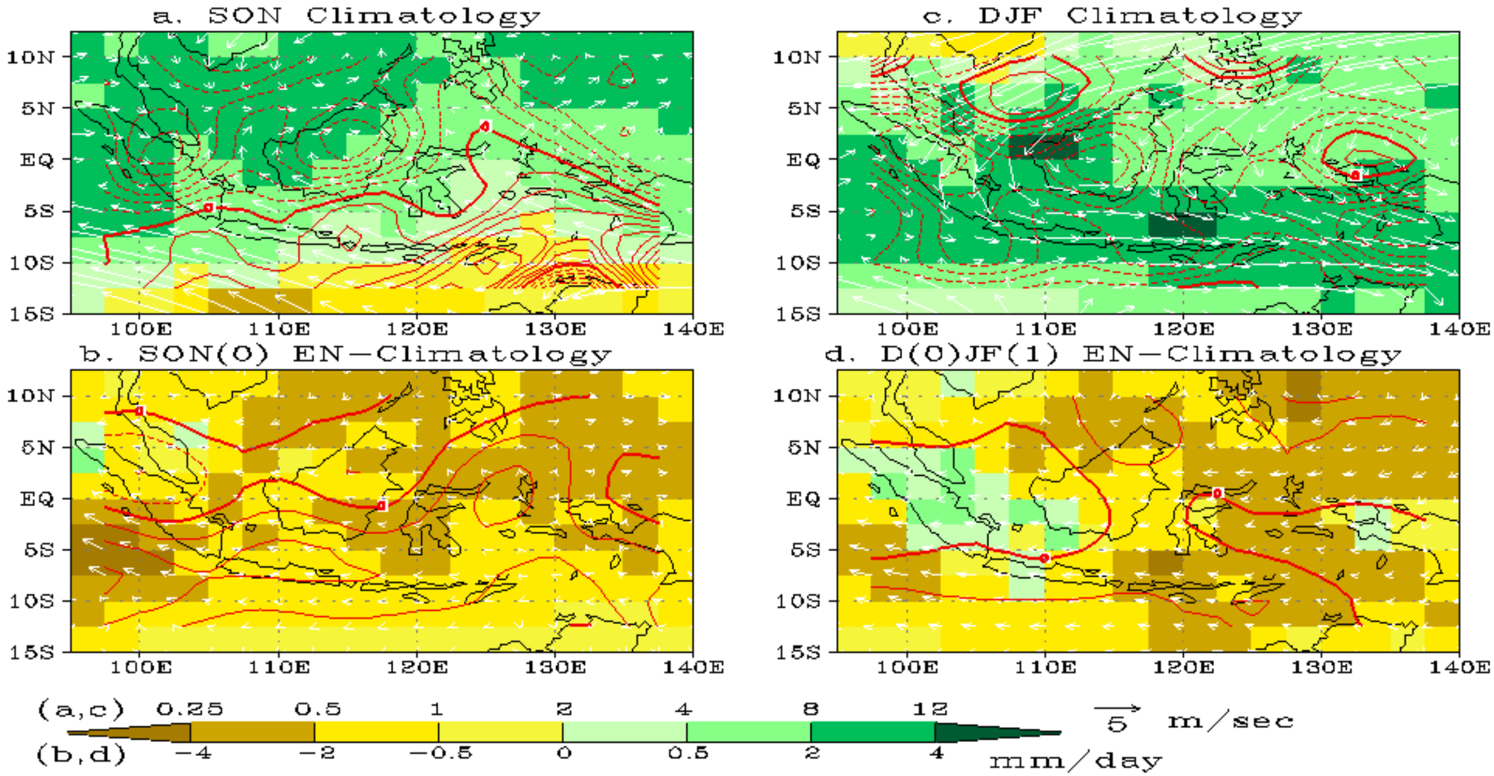


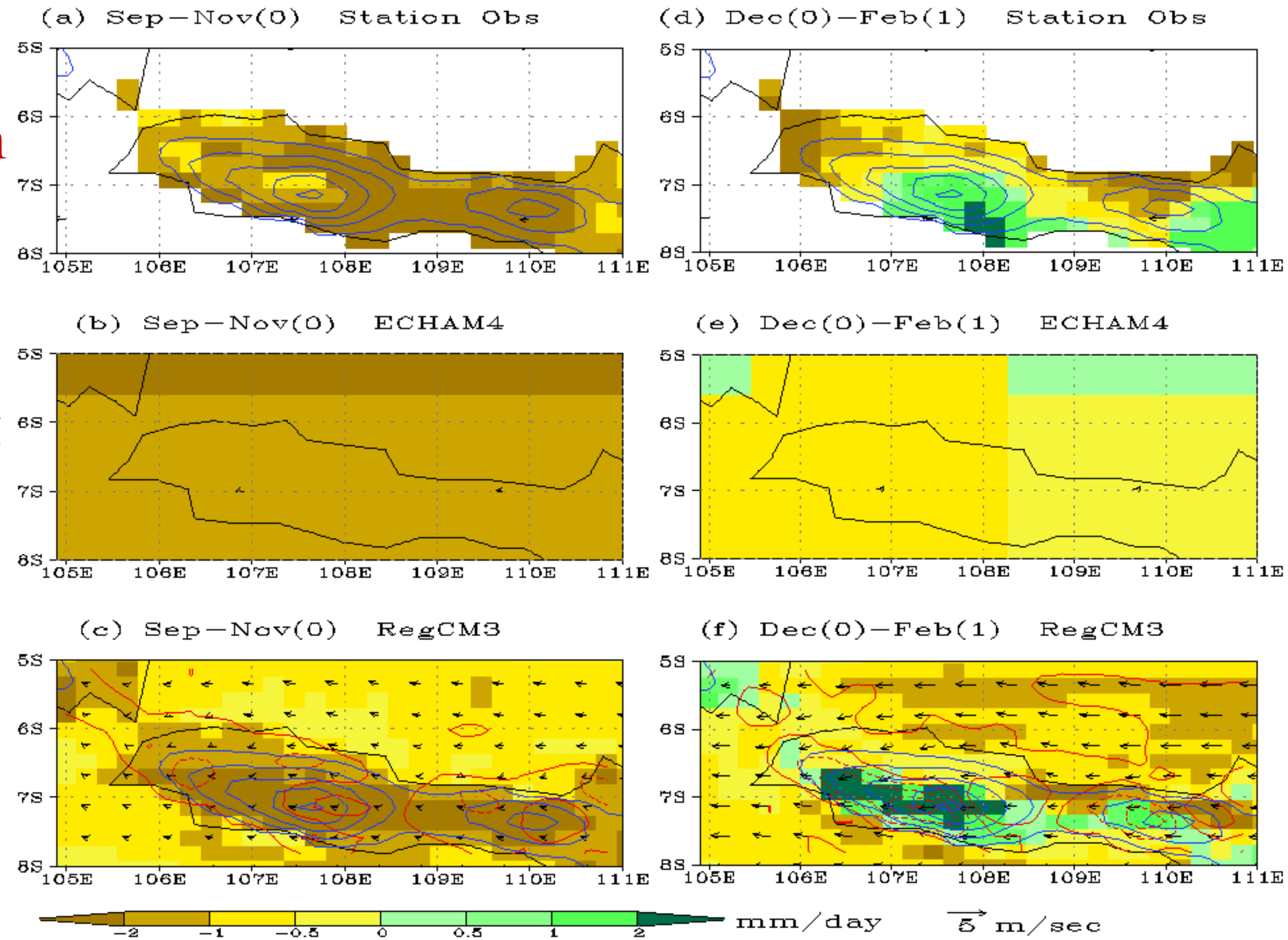
Fig.1 Climatology (1979−2000) and (El Nino − climatology) composite of CMAP precipitation (mm/day; shaded), and NNRP winds (vector) and divergence (red contours with interval of 0.5e−6/sec, divergence is thin solid, convergence thin dash, zero−curves thick solid) at 925hPa, for SON (a, b), and DJF (c, d). El Nino years used for the composite are: 82/83, 86/87, 87/88, 91/92, 94/95, 97/98. El Nino developing years are denoted by (0).

In SON (left), spatially coherent dry anomaly in El Nino years.
In DJF (right), dipolar pattern of El Nino impact: dry anomaly on north coast, but wet anomaly on south coast.

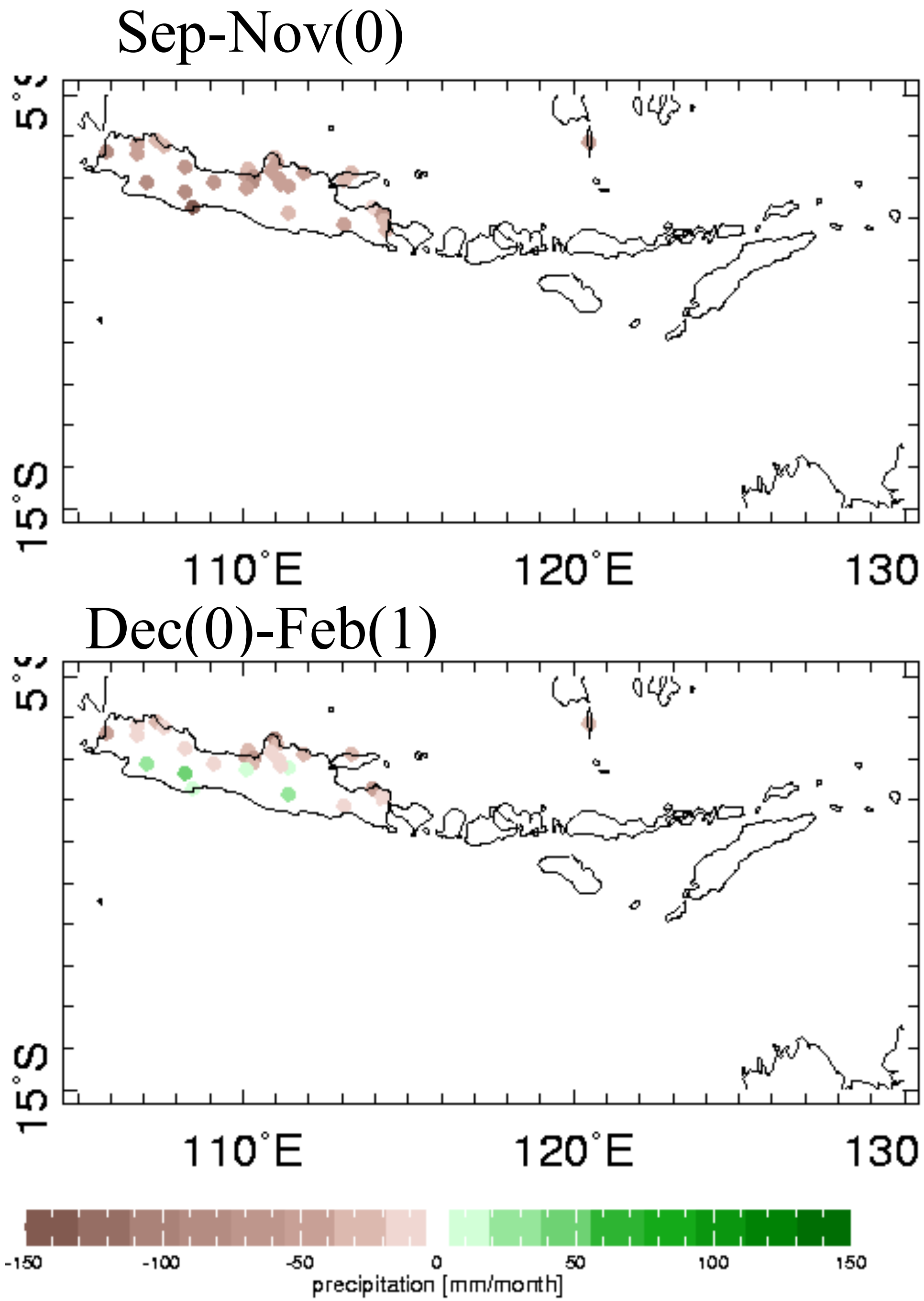
Observation

ECHAM4.5 GCM

RegCM3



(El Nino – Climatology) composite of seasonal precipitation (mm/day; shaded), low-level winds (m/s, vector) and divergence (red contour interval is 1e-5 in c&f). Top panels: observation, middle: ECHAM4, bottom: RegCM3. Terrain heights are shown by blue contours (interval 200 m)
El Nino years: 72/73, 82/83, 86/87, 91/92, 94/95, 97/98; Java Indonesia

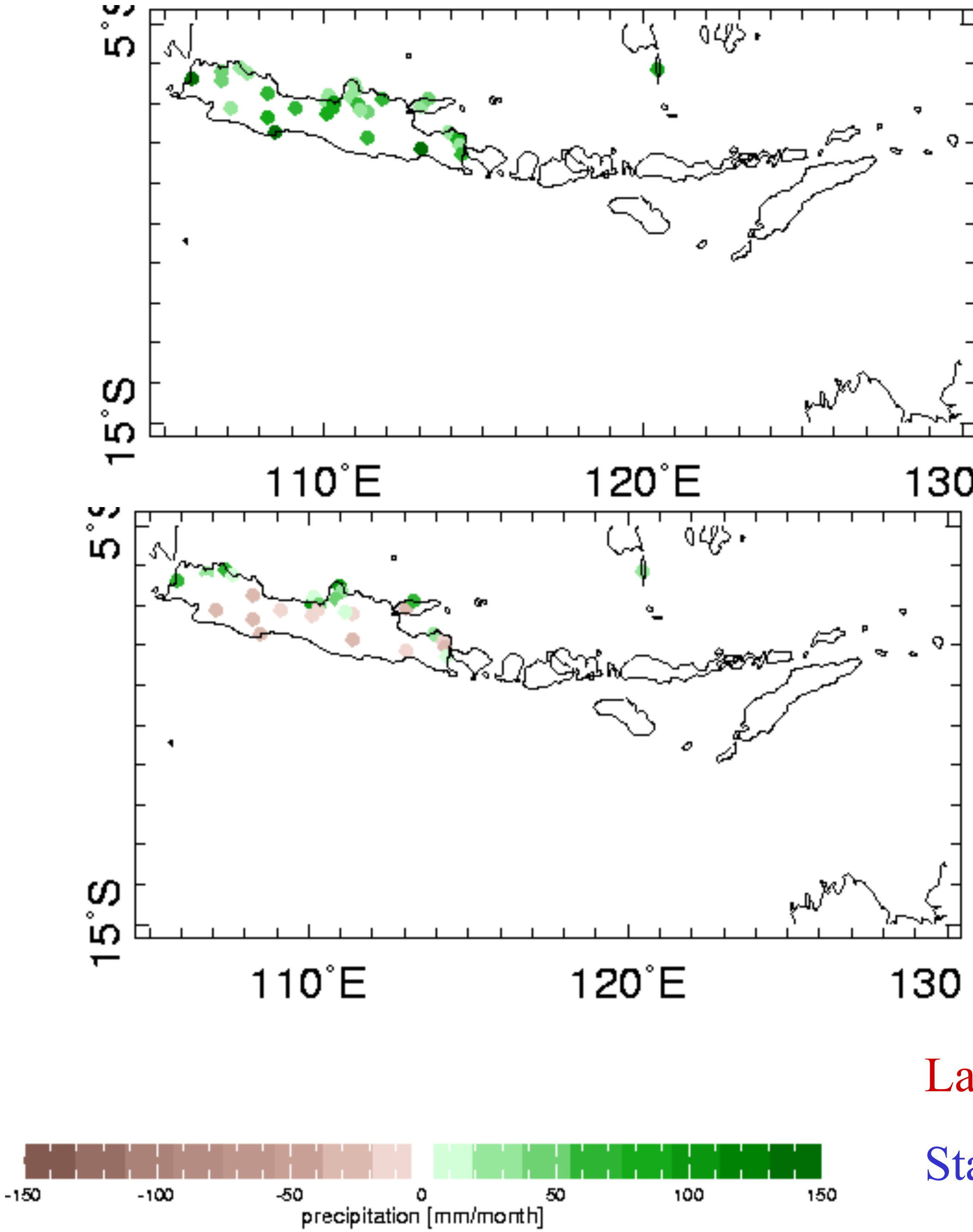


STATION OBSERVATION:

In SON, spatially coherent dry anomaly in El Nino years.

In DJF, dipolar pattern of El Nino impact: with dry anomaly on north coast, but wet anomaly on south coast.

El Nino year
Station Precipitation Anomaly
(EN-Climatology Composite)



Sep-Nov(0)

Dec(0)-Feb(1)

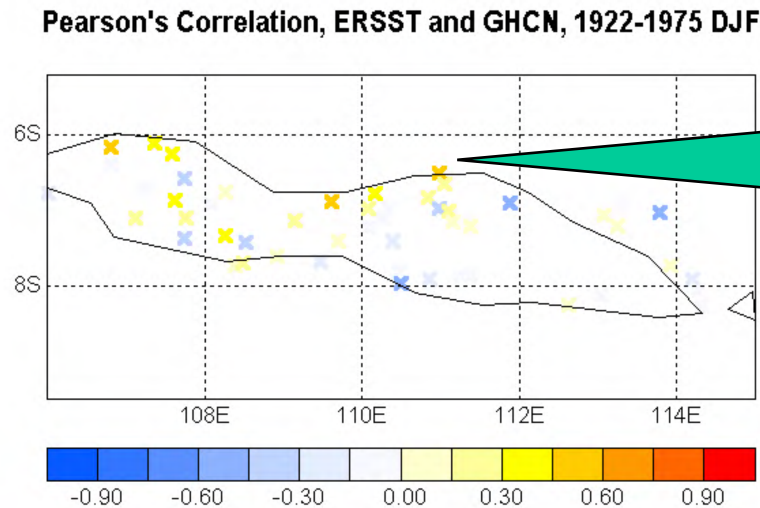
La Nina year

Station Precipitation Anomaly

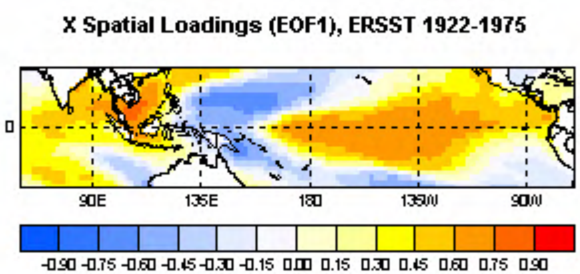
(LN-Climatology Composite)

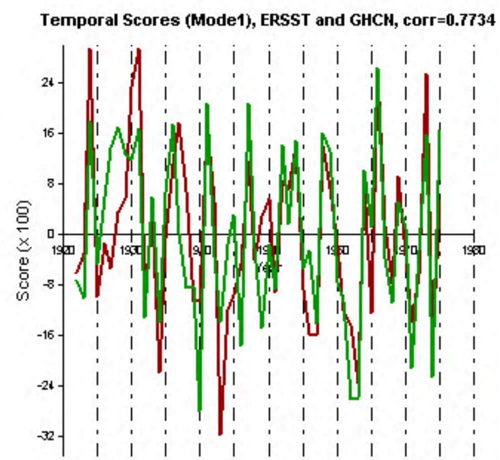
Canonical Correlation Analysis, CCA (ERSST & GHCN rainfall)

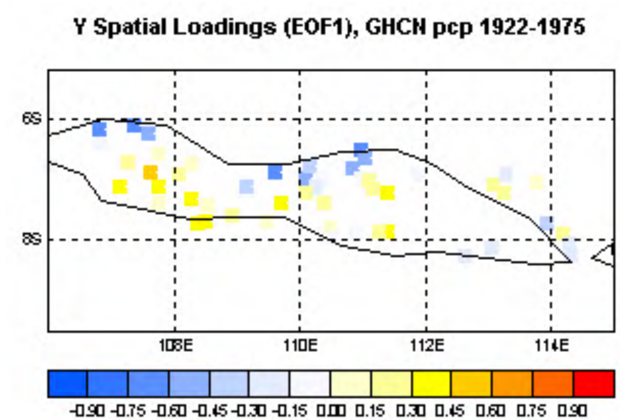
1922-1975 Dec-Feb (**DJF**)



Low predictability in DJF, but slightly enhanced predictability at north coast



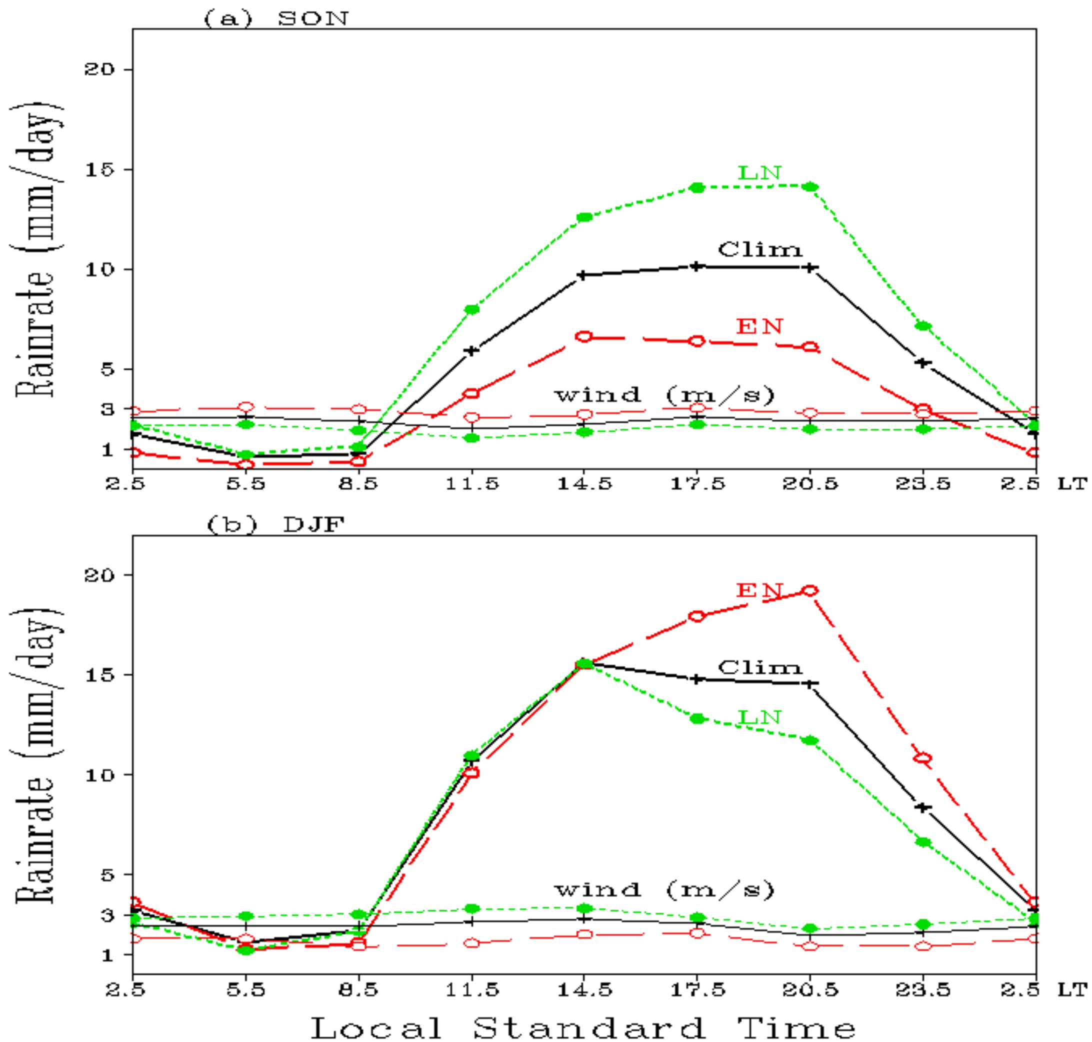




SST ENSO pattern

Java rainfall dipolar pattern

Inverse relationship *between monsoonal wind speed and diurnal cycle*



EN wind anomalies & mean winds same direction

EN wind anomalies & mean winds opposite direction

Fig.7 Diurnal cycles of RegCM3 rainfall (mm/day, thick) and wind speed (thin, m/s) over the whole area of Java Island in SON (a) and DJF (b) for climatology (black), El Nino year composite (red long dash), and La Nina year composite (green short dash). "LT" denotes the local standard time at Jakarta. Wind speeds at 10 m are plotted with the same scale, but with unit m/s.

Dry easterly monsoon WT1 & WT2

Strong westerly monsoon WT3

Quiescent monsoon WT4

Strong westerly monsoon WT5

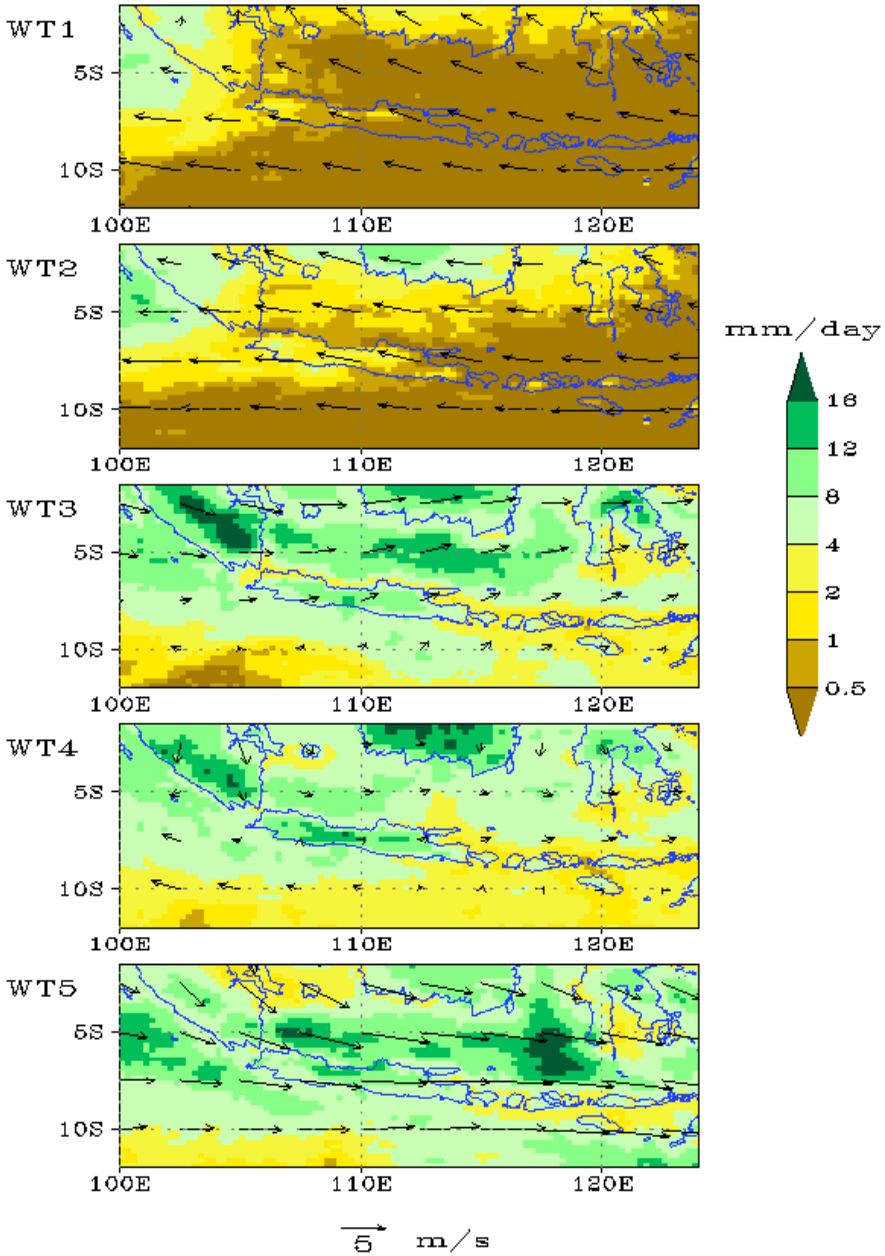


Fig.8 Climatology of CMORPH (2004–2007) precipitation WT1–5 (mm/day; shaded) and NNRP reanalysis winds at 850 hpa (m/s).

Intraseasonal variability:

weather typing analysis

Frequency of Weather Types (%)

Blank bar: Climate, Red bar: El Nino, Green bar: La Nina

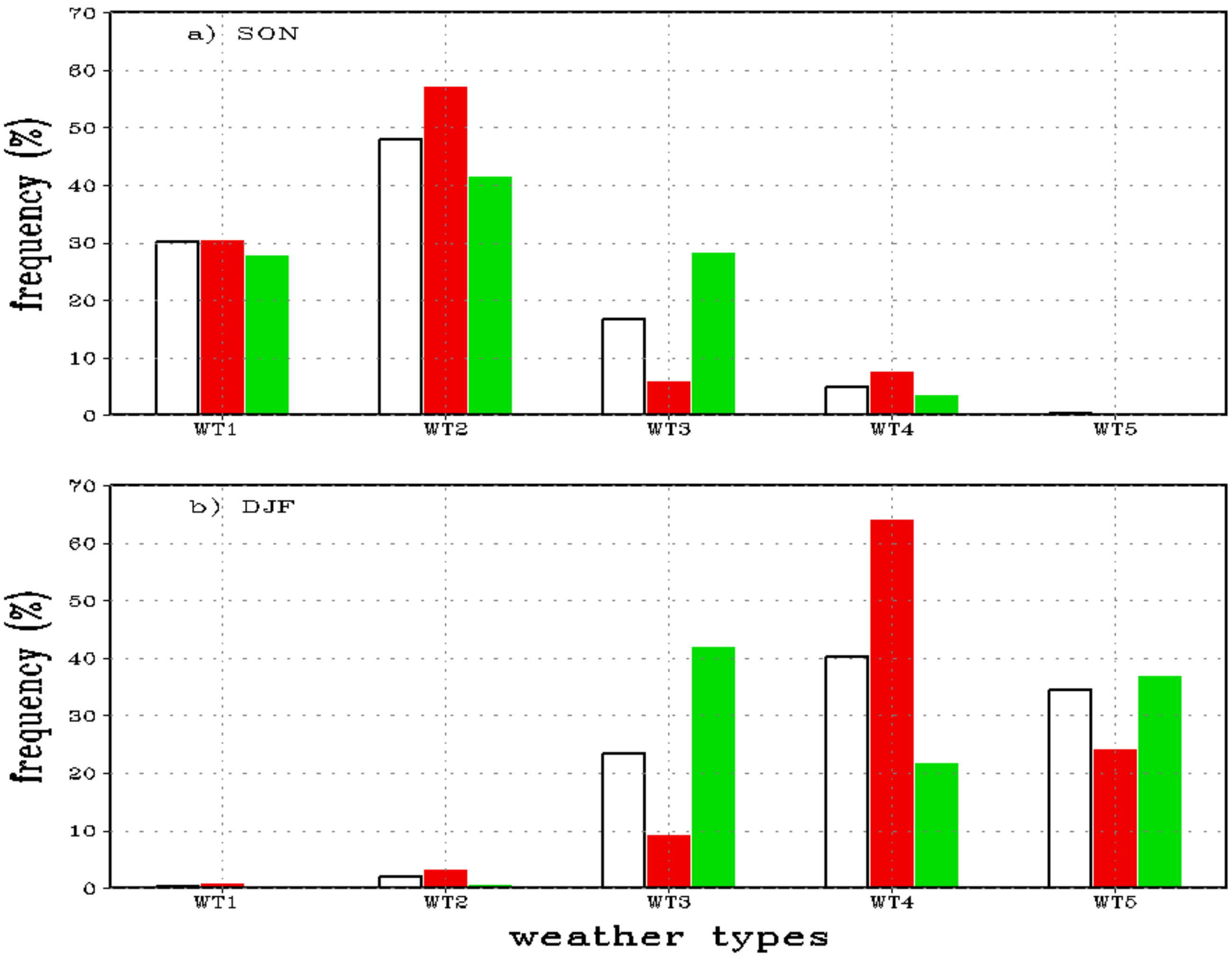


Fig.9 Frequencies of five weather types, WT1 to WT5, in all years (blank left bar), El Nino years (red middle bar), and La Nina years (green right bar) in the SON and DJF season, respectively.

Diurnal cycle of observed and simulated rainfall for the 5 WTs

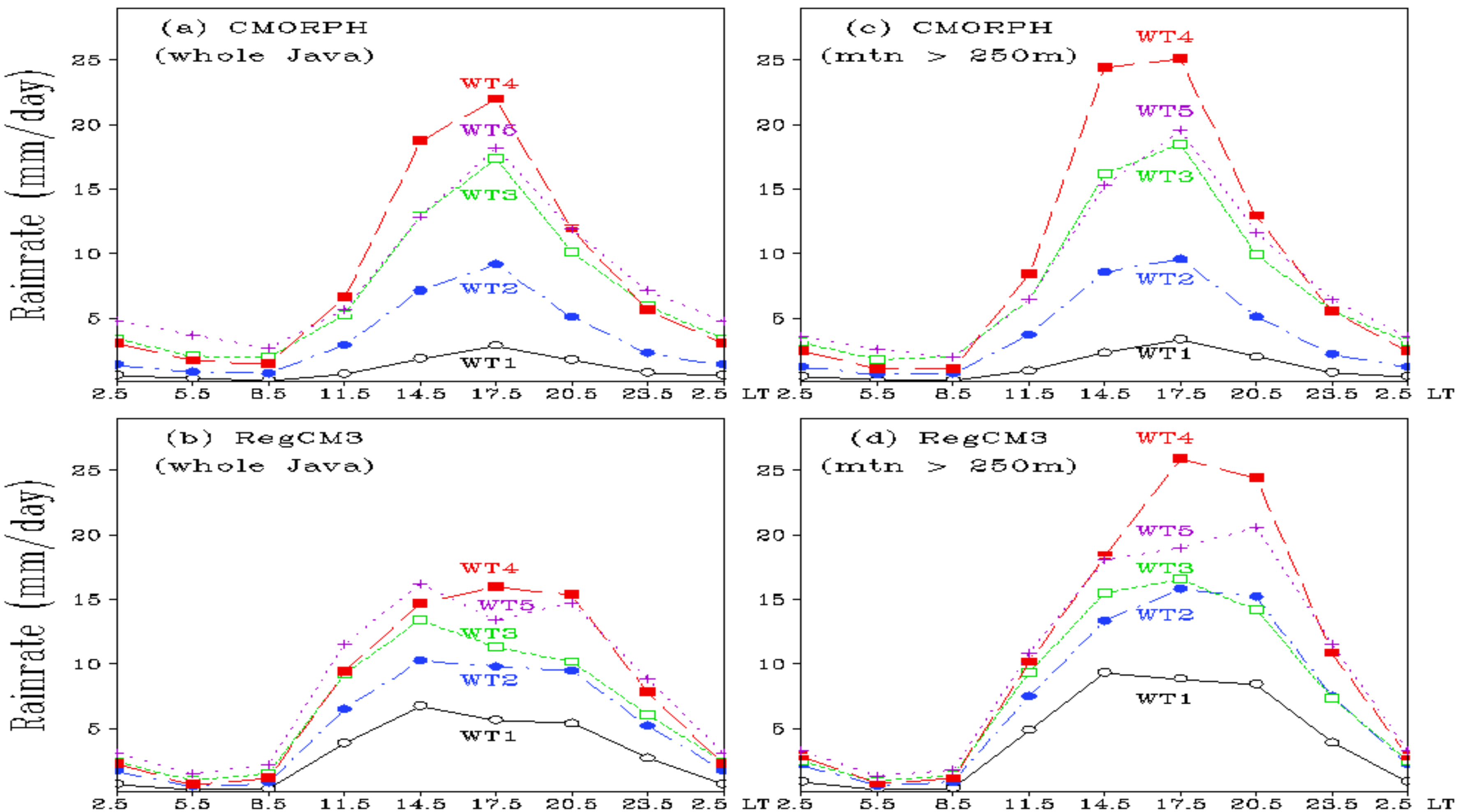


Fig.10 Diurnal cycles of CMORPH and RegCM3 rainfall (mm/day) over the whole area of Java Island (a, b) and over mountainous regions (terrain height > 250m) (c, d) for weather types: WT1 (black), WT2 (blue), WT3 (green), WT4 (red), WT5 (purple). "LT" denotes the local standard time at Jakarta Indonesia.

SUMMARY of Part 2a

MULTI-SCALE PROCESSES (for Java Dipole):

El Nino (with southeasterly wind anomalies)
Weaken northwesterly monsoon in DJF

→ Strengthen diurnal cycle of winds

→ Strengthen sea-valley-breeze convergence,
Produce more rainfall over mountains and less rainfall over plains.

Key: Inverse relationship between monsoon intensity and diurnal cycle !!!

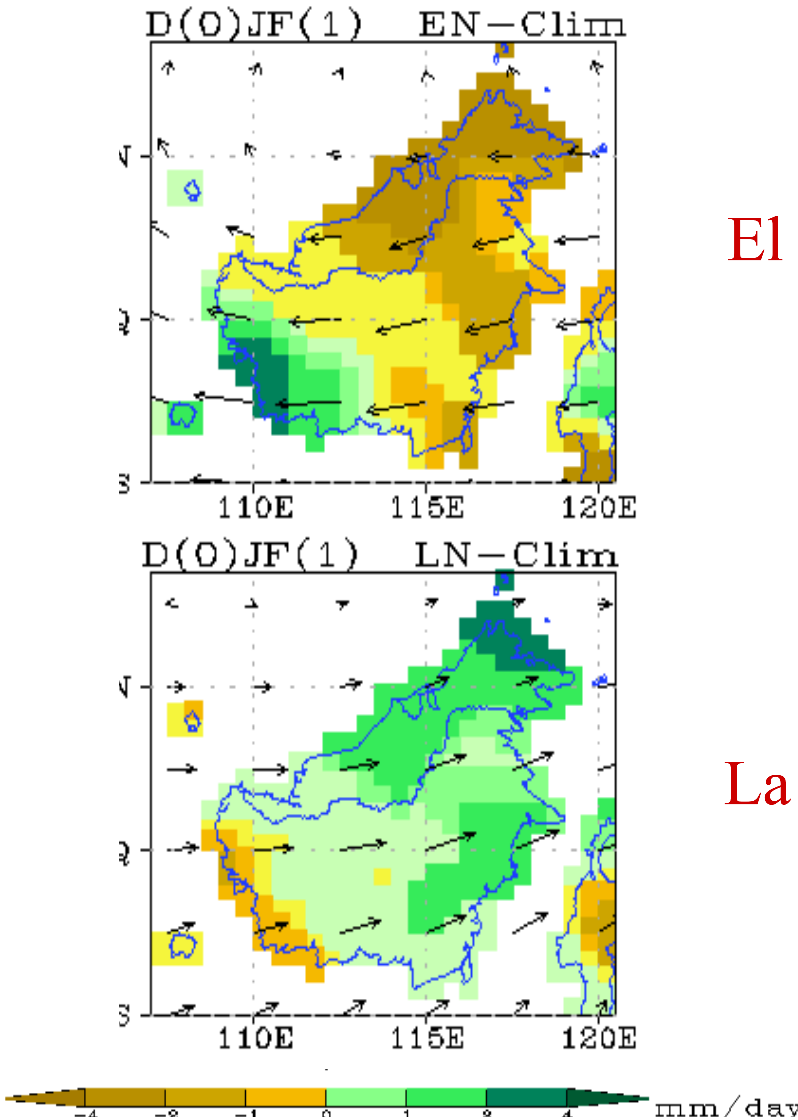
(Qian et al. (2010) J. Atmos. Sci.)

2b. Wake Effect: What is the mechanism for an ENSO-related Dipolar Pattern of rainfall variability over Borneo Island?

Dipolar Pattern:

Opposite signs of **rainfall anomalies** over southwest vs central & northeast Borneo in DJF (Dec-Jan-Feb) associated with ENSO

(Qian et al, 2013, J. Climate)



El Niño years

La Niña years

2. Wake Effect

Five Weather Types

(WT 1-5)

red arrows: 850hPa winds

black arrows: sea-breezes (quikSCAT)

Color shade: CMORPH precipitation

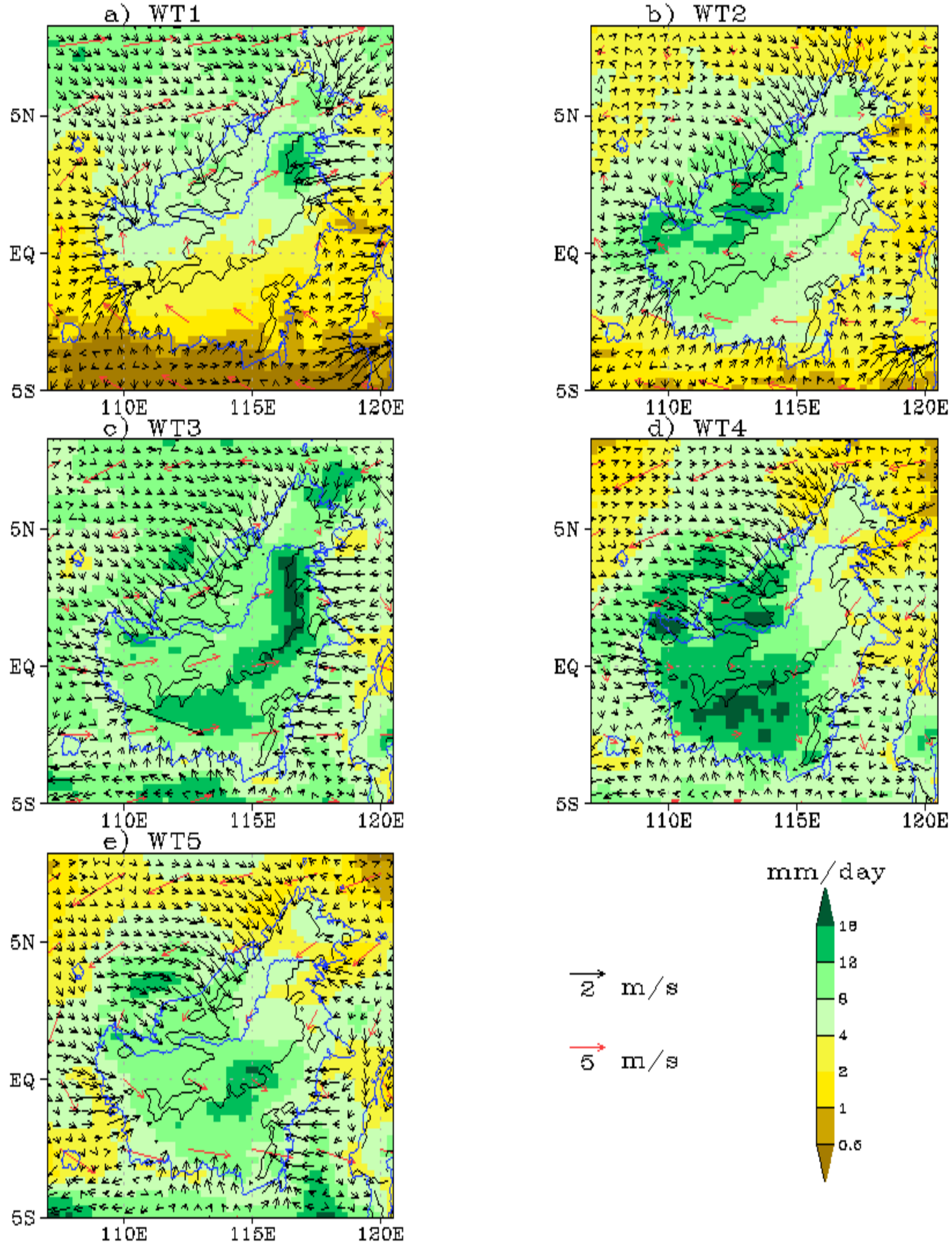


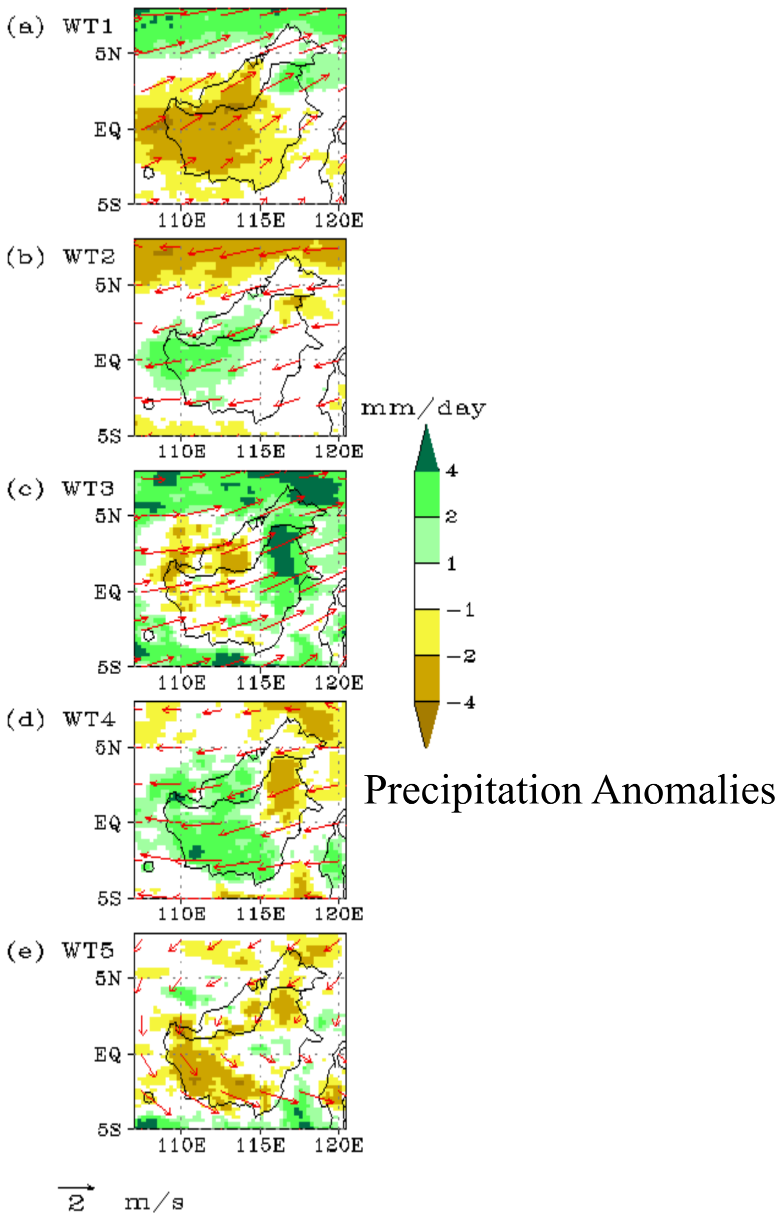
Fig.4 Averaged CMORPH precipitation (mm/day, shaded), NRP 850hPa winds (m/s, red arrows), and QuikSCAT sea breezes at 10 m (black arrows, local evening pass minus daily mean) for the 5 WTs. The thin black curves illustrate terrain heights of 250 m using the USGS 10-min data.

Rainfall & 850hPa Wind Anomalies of Weather Types (WT 1 – 5)

<u>2b. Wake-Effect</u>:

more rain on the wake- or lee-side of the island – for every WT

(Qian et al. 2013 J. Climate)



10 Anomalous CMORPH precipitation (mm/day) and anomalous NNRP 850hPa winds (m/s) for the 5 weather types. WT-frequecy-weighted averaged climatologies have been substracted to show the anomalies for the WTs.

Conclusion

1. Rainfall is concentrated over islands because of
(a) Sea breeze convergence
(b) Mountain-valley breeze, and
(c) cumulus merger in the sea breeze convergence zone

2a. Monsoonal Damping Effect: *Inverse relationship between the monsoonal wind speed and the diurnal cycle of land-sea & mountain-valley breezes.*

2b. Wake-Effect: *More rainfall on the shielded wake-side of the* ***Borneo Island*** *caused by the strengthened sea-breeze convergence.*

(Multi-scale processes associated with MJO - talk at NTU on 23 Sept)

ENSO Impacts on seasonal rainfall in Western MC

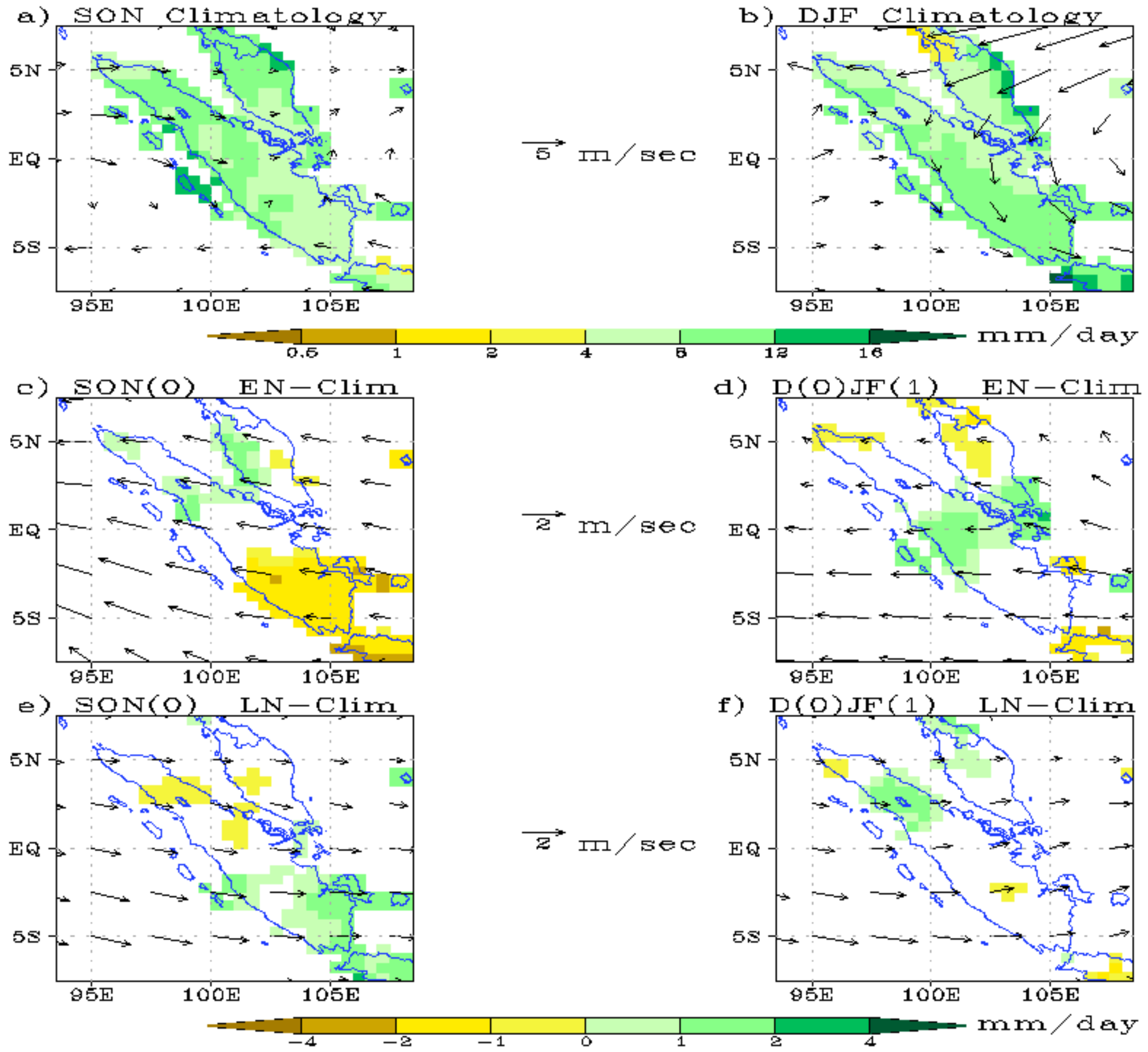


Fig.2 Climatology (top panels) and (ENSO – climatology) composite of GPCC precipitation (1901–2007) (mm/day; shaded) and NRP winds (1979–2007) (vector) at 850hPa, for SON (a,c,e), and DJF (b,d,f). The ENSO developing years are denoted by (0). Composite of 22 El Nino years are in (c,d). Composite of 25 La Nina years are in (e,f). Differences significant above 90% level of t-test are shown.

MJO Impacts on the MC rainfall

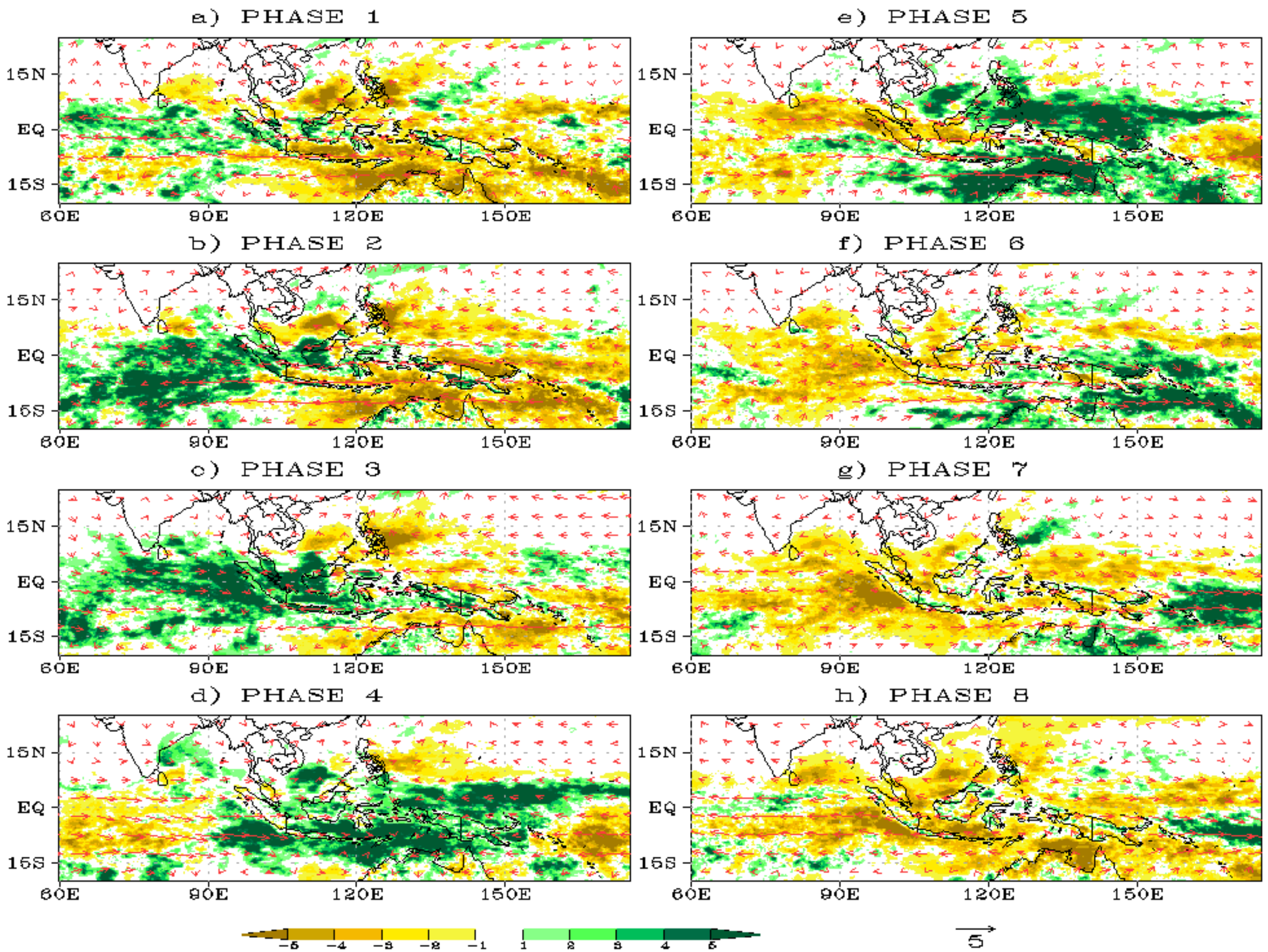


Fig. 4 Composite anomalies of the CMORPH precipitation (mm/day; shaded) and the NCEP-DOE reanalysis winds at 850 hPa (vector) in MJO phases 1-8 in DJF.

MJO Impacts on the MC rainfall

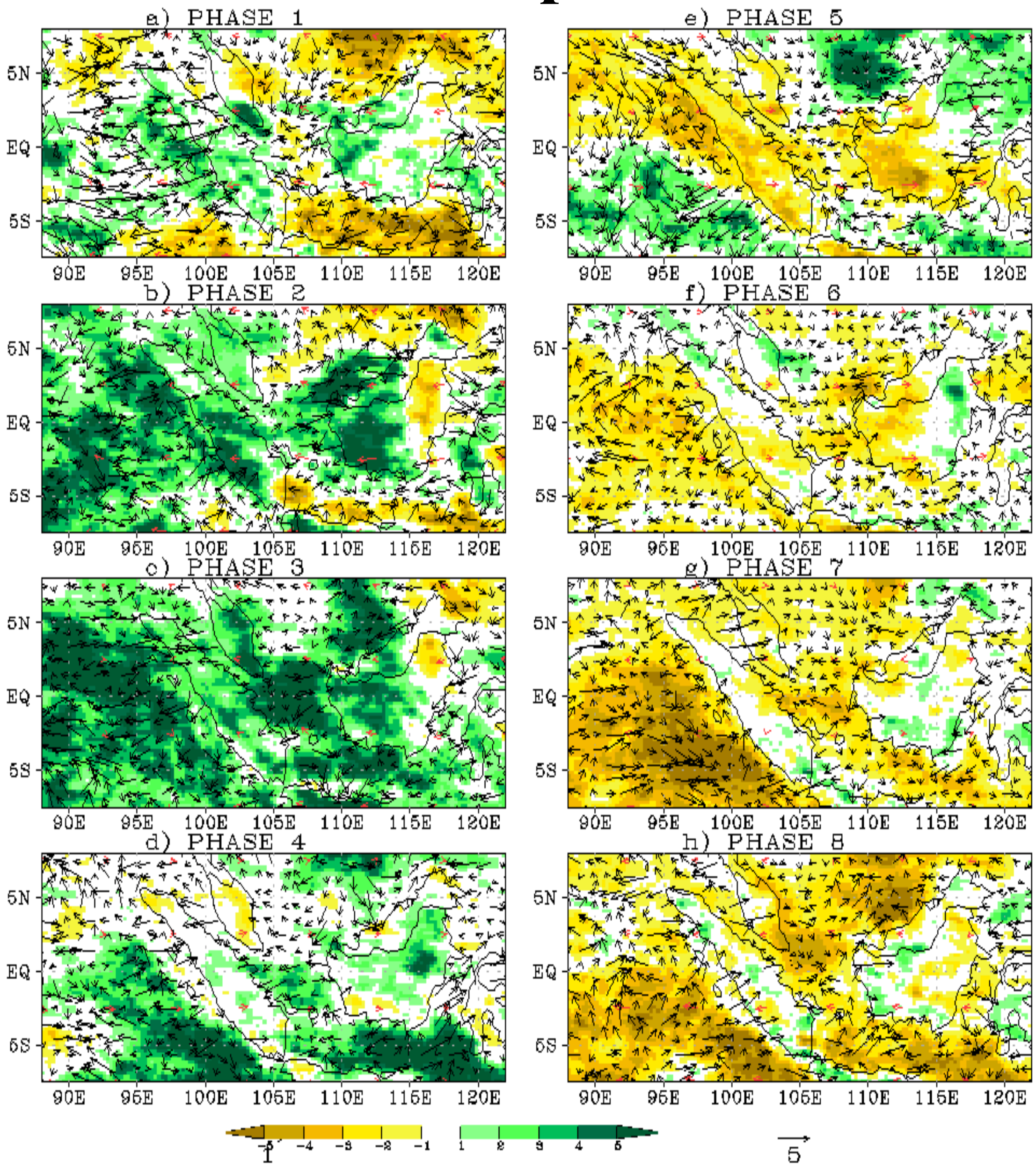


Fig. 4 Composite anomalies of the CMORPH precipitation (mm/day; shaded), the NCEP-DOE reanalysis winds at 850 hPa (red arrow), and the quikSCAT sea breezes (black arrow) in MJO phases 1-8 in DJF.

Singapore is wetter in MJO phases 1-3 and drier in MJO phases 4-8. It is on the margin of positive and negative rainfall anomalies in MJO phase 4.

Is it beautiful?!