Weather regimes in the tropics at regional-scale: the example of ENSO and Indonesia

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Weather regimes (WR) ?

- « *particles* » in the large-scale atmosphere's phase space (Ghil and Robertson, 2002)

- characterized by their *recurrence*, *persistence* and the *geographically fixed characters of the associated flow features*

- their preferred time scale is between synoptic scale (days/week) and seasonal scale (from ~ 90 to 180 days) = **intra-seasonal variance (ISV)**

- In extratropics, WRs are usually defined for a given season (more frequently for winter semester) and using usually filtered data (at least to remove synoptic scale) at hemispheric or regional scales

- Less analyses of the WRs in the tropical zone, but a lot about specific time-scale (for example, analysing ISV should be viewed as a complementary « wave » point of view of WR ...)

Tropical atmospheric variability ?

- Large variance due to (1) diurnal cycle (i.e. convection on continents, land, sea and valley breezes etc.) and (2) annual cycle (i.e. shift of the intertropical convergence zone - ITCZ- and monsoon circulation)

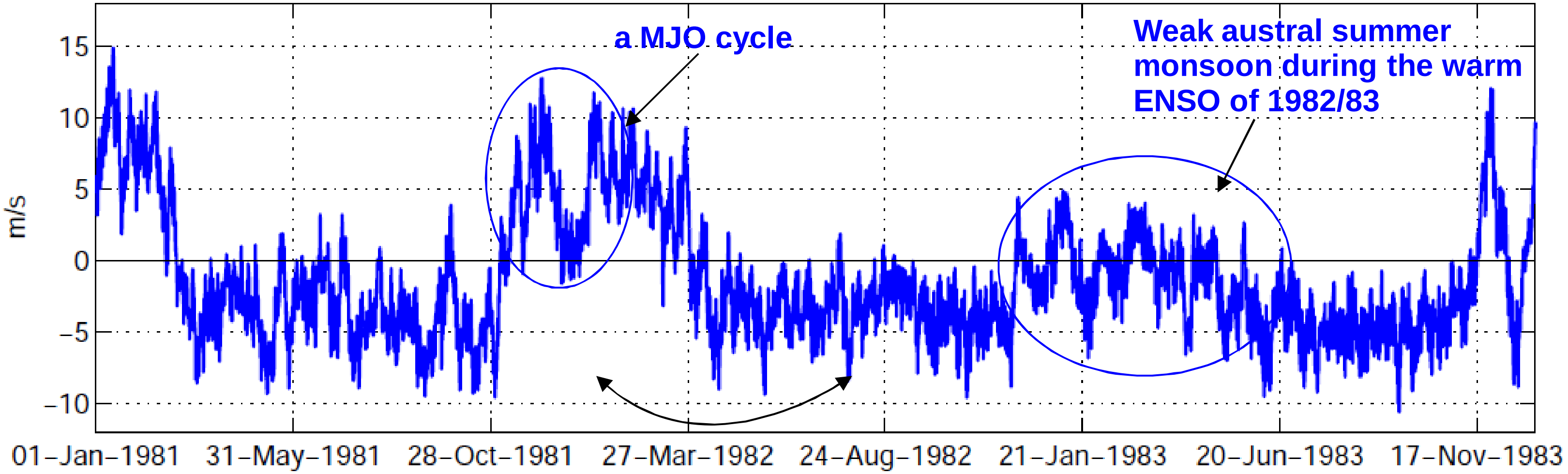
- ISV is dominated by MJO (~ 25-60 days), modulated in space (max over Indian-West Pacific longitudes) and in time

- Large Ocean-Atmosphere coupling, with a strong dependency to basic state (including sea surface temperatures - SST-).

- Interannual time scale (2-8 years) is dominated by El Nino Southern Oscillation -ENSO- phenomenon, with a peak intensity around Xmas and an approximate duration of 12-18 months

Illustration of the difference tropics vs extratropics (1)

6h 850 hPa zonal wind 7.5S−2.5S & 105E−120E (from NCEP 2)

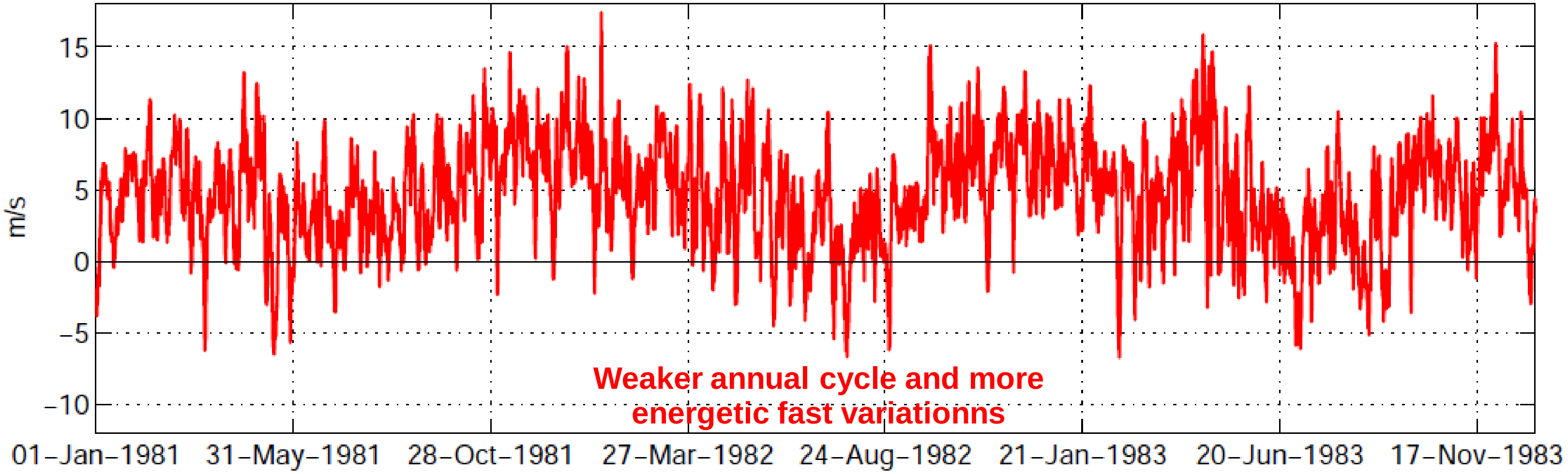


a MJO cycle

Weak austral summer monsoon during the warm ENSO of 1982/83

Asymmetric annual cycle

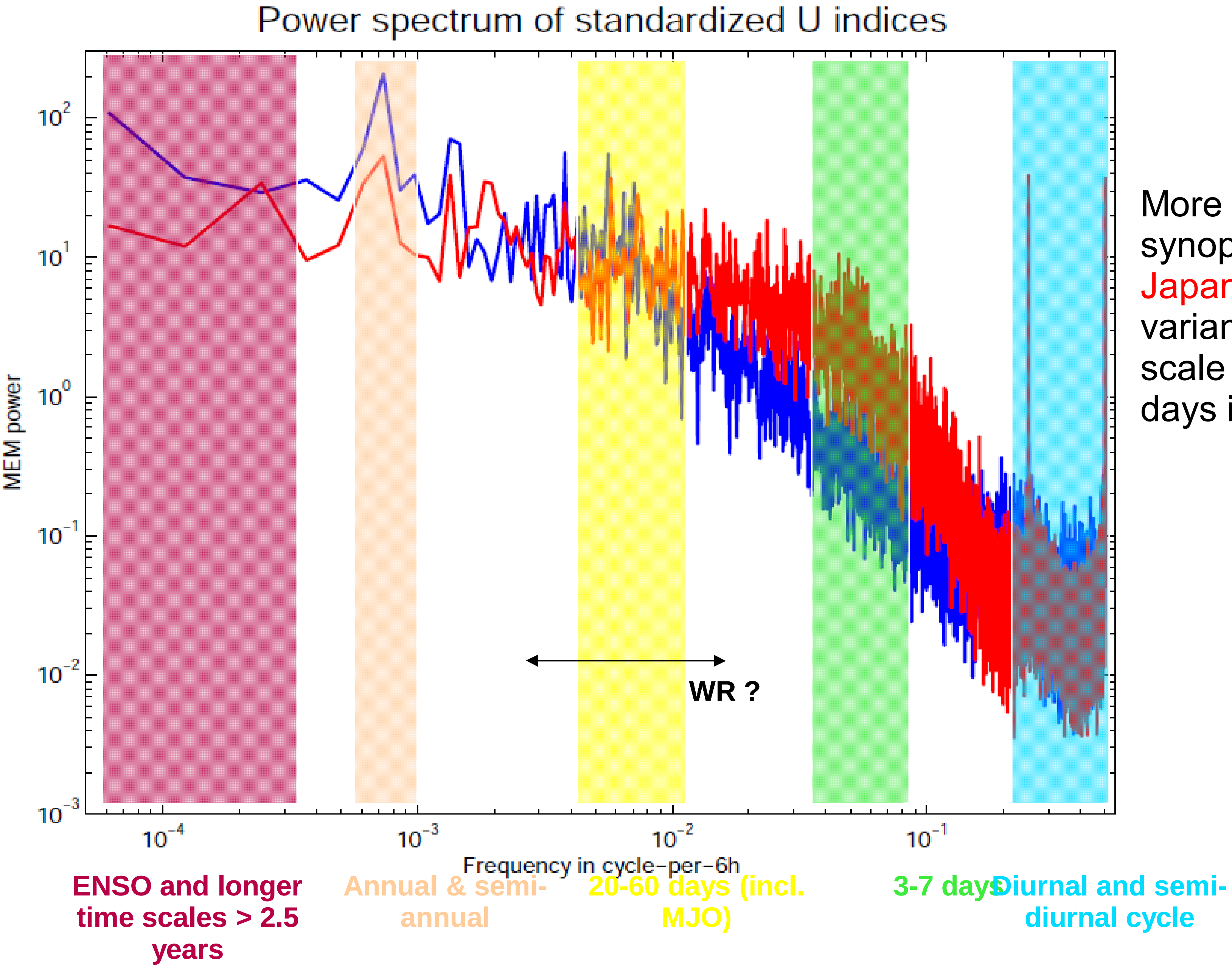
6h 850 hPa zonal wind 40−50N & 120E−135E (from NCEP 2)



Weaker annual cycle and more energetic fast variationns

3 years (from Jan 1 1981) of 6h of U850 hPa over Java Sea and off Japan (positive values are westerlies & negative values are easterlies)

Illustration of the difference tropics vs extratropics (2)



More variance at synoptic scale off Japan while more variance at longer scale than 30-40 days in Java Sea

This study

- Maritime Continent = myriad islands of different sizes (some almost flat, but usually mountainous) surrounded by warm waters > 27°C along the equator

- one of the pole of ENSO phenomenon

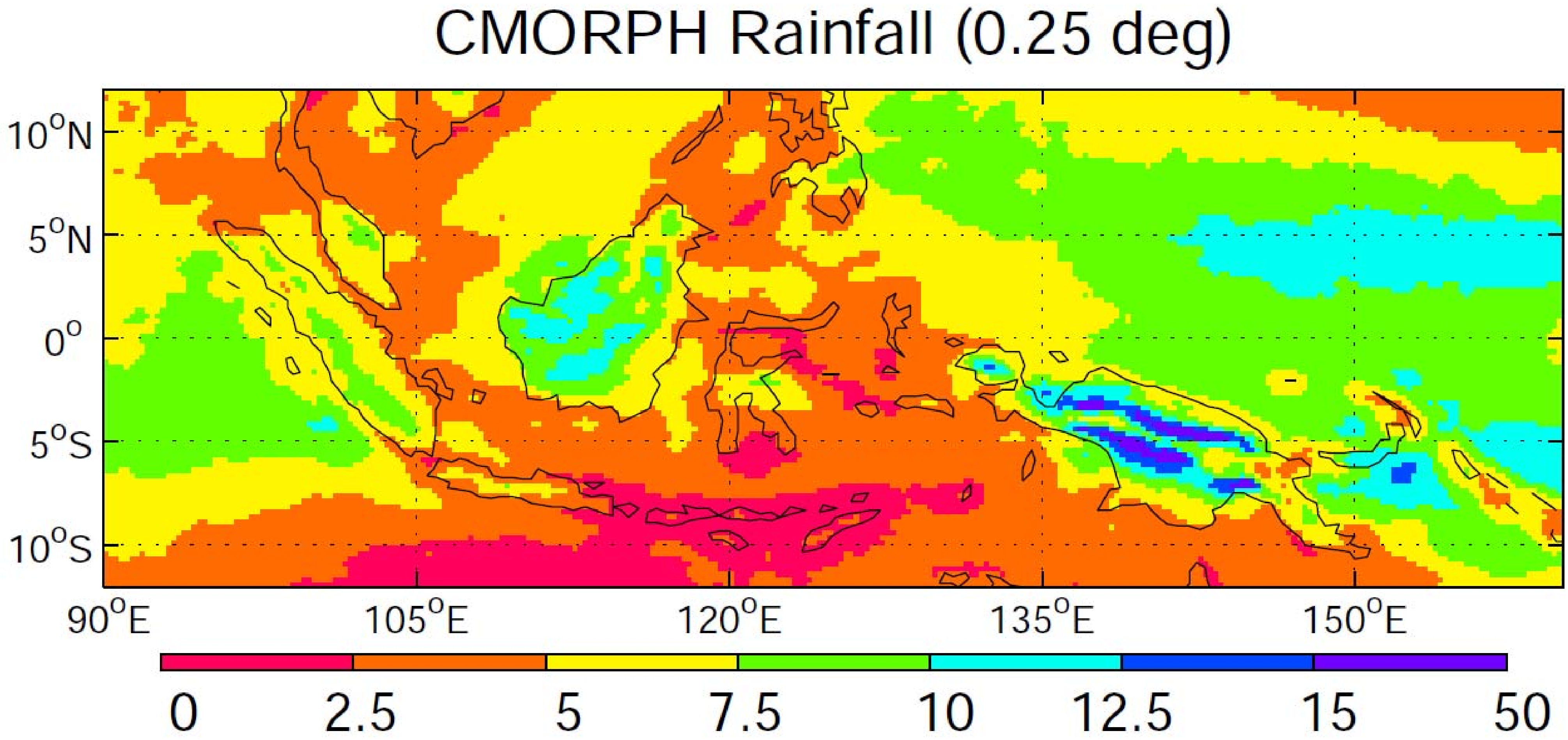
- starting point ?

few WRs around the Maritime Continent considering **unfiltered data** (i.e. including the seasonal cycle) as **a coarse-grained and unified approach of the multiscale atmospheric variation**

- The goal is not to find multiple equilibrium states in the atmosphere's phase space but merely to **analyze the continuum of atmospheric variations from diurnal cycle to interannual variations across the annual cycle using the WR point of view**

- A WR could be thus interpreted as either (1) a specific phase of the annual cycle or (2) a phase of MJO or (3) reveal a persistent anomalies related to ENSO. Any small-scale, or even synoptic scale, occurring randomly in space, will be filtered out

- One advantage of this approach is **to avoid to separate time scales** (which interact in a complex way in nonlinear system as climate)



Role of the ITCZ + shape/size of islands + topography

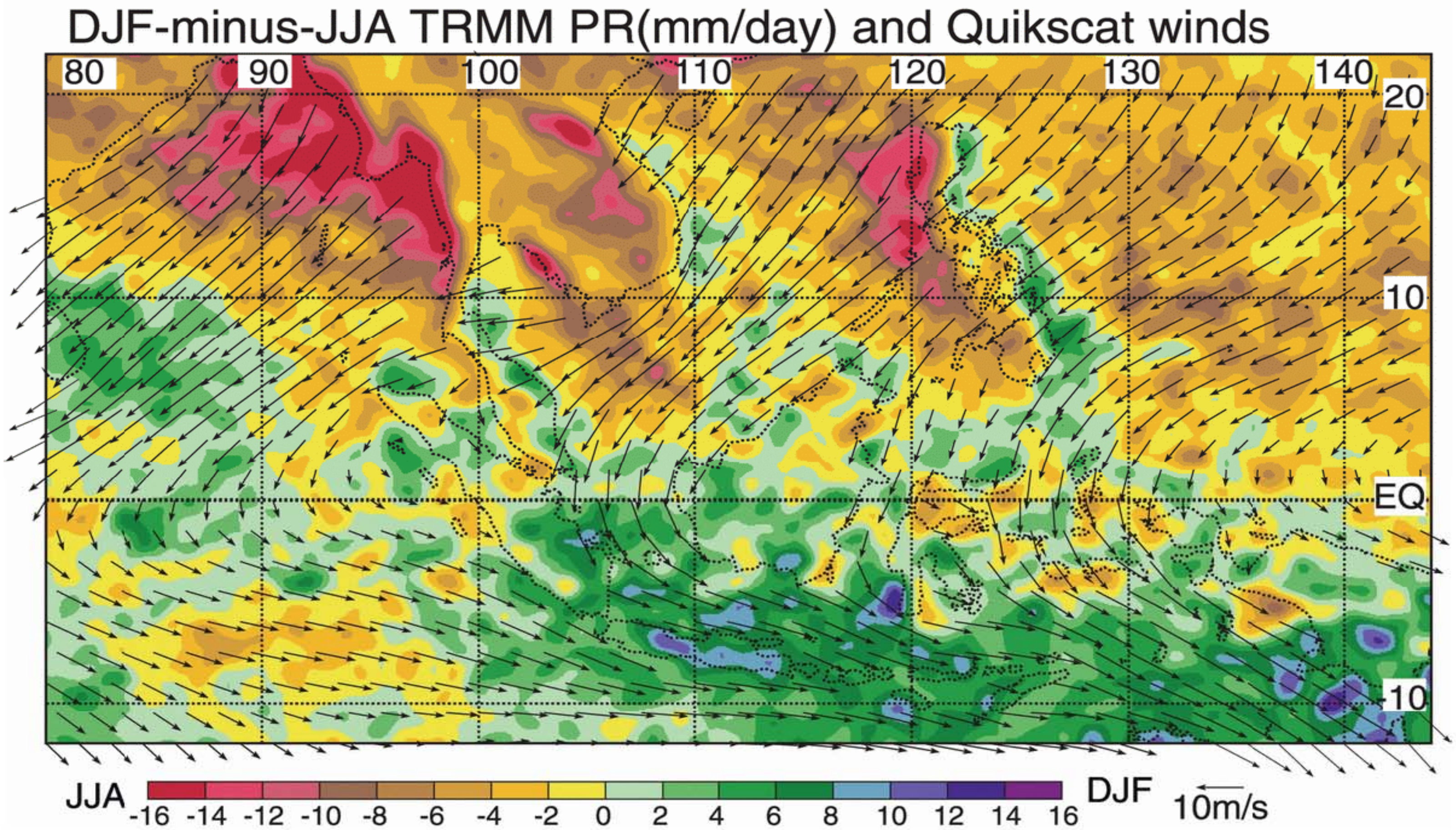
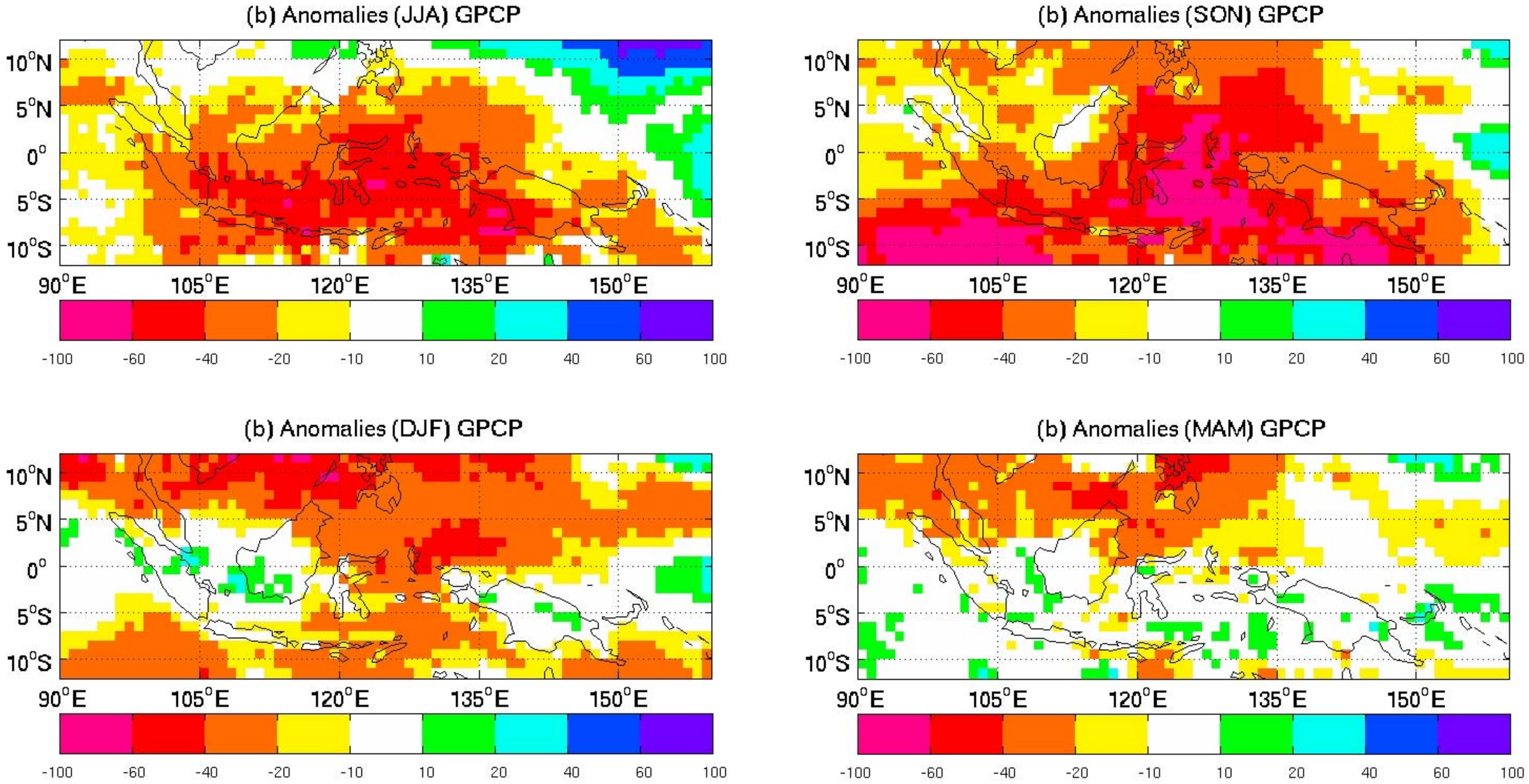


Figure 1. Differences of TRMM Precipitation Radar data and QuikSCAT winds between boreal winter and boreal summer (DJF minus JJA). Warm colors are the boreal summer monsoon regime and cool colors are the boreal winter monsoon regime. (from Chang *et al*. 2005a)

(Robertson et al., 2011)

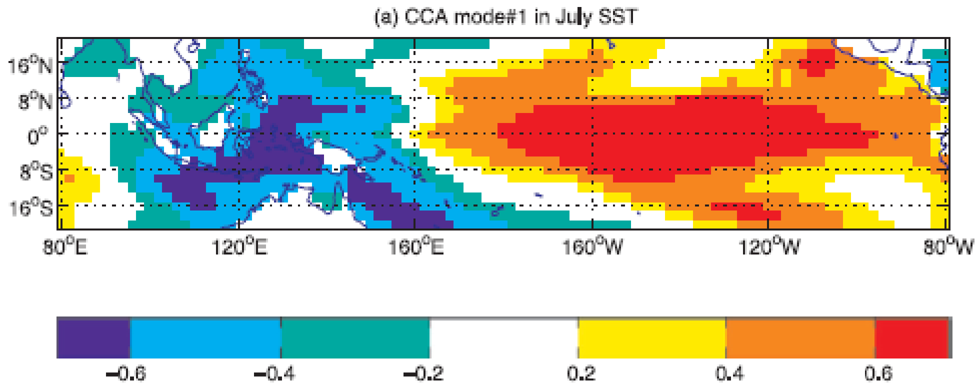
Annual cycle : monsoon + topography



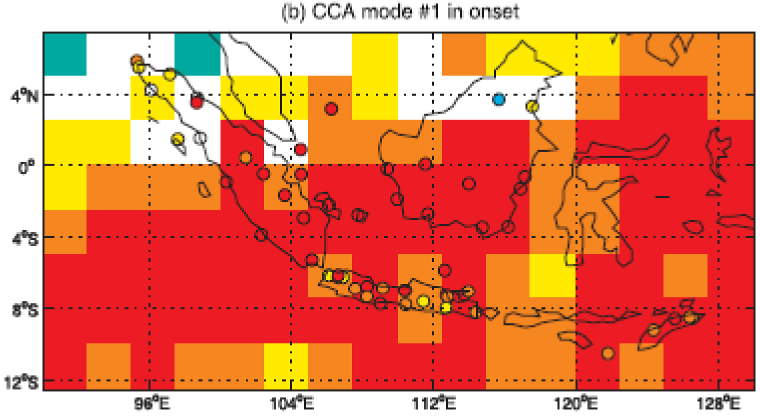
(Warm – Cold ENSO seasonal composite in % of the mean 1 ° x 1 ° GPCP data)

Impact of ENSO is spatially consistent accross MC in JJA and especially in SON and disagreggates itself, especially on islands from DJF (that is the usual peak of ENSO events)

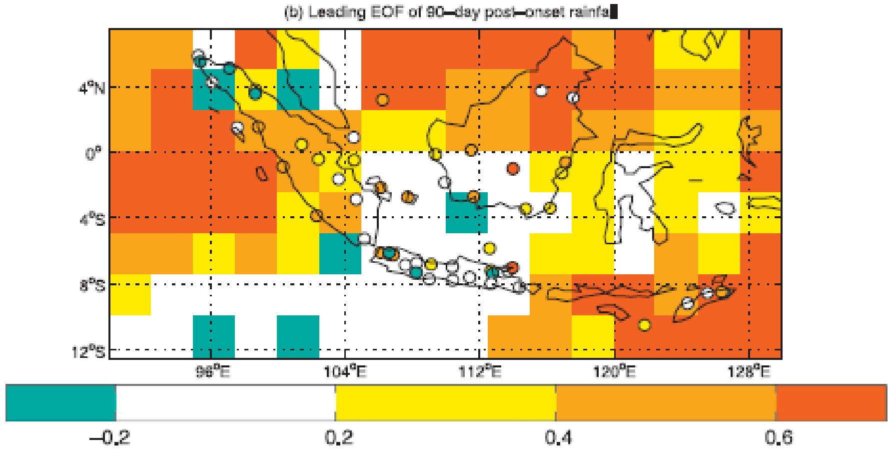
(a) CCA mode#1 in July SST



(b) CCA mode #1 in onset



(b) Leading EOF of 90-day post-onset rainfall



(c) Leading EOF of SOND residuals

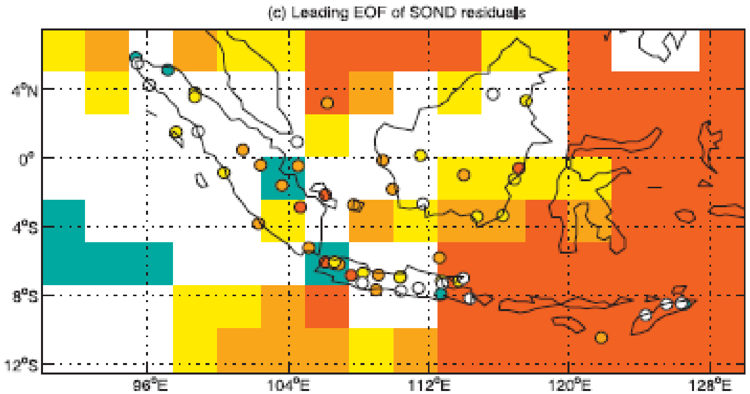


FIG. 3. (a) Individual standardized anomalies of rainfall total for the 90-day period after the local onset date at the 128 CMAP grid points (dots) with the SAI (solid). The dashed horizontal lines delineate the 95% confidence interval of a set of 128 white noise time series. (b) Leading EOF of postonset 90-day amounts in CMAP (shading) and GSOD (dot). (c) Leading EOF of SOND residuals in CMAP (shading) and GSOD (dot). Units in (b) and (c) are correlations with the respective principal component time series.

(Moron et al., 2009)

SON signal ?
- mostly the phase of the regional-scale onset strongly tighted to ENSO (warm = delayed onset)
- removing onset signal from SON decreases the spatial coherence of SON rainfall anomalies

Data & methods

- daily 850 hPa winds from NCEP II covering the transition from dry season to the core of wet season across monsoonal Indonesia (~ south of equator) from August to February (212 days) on 1979-2006

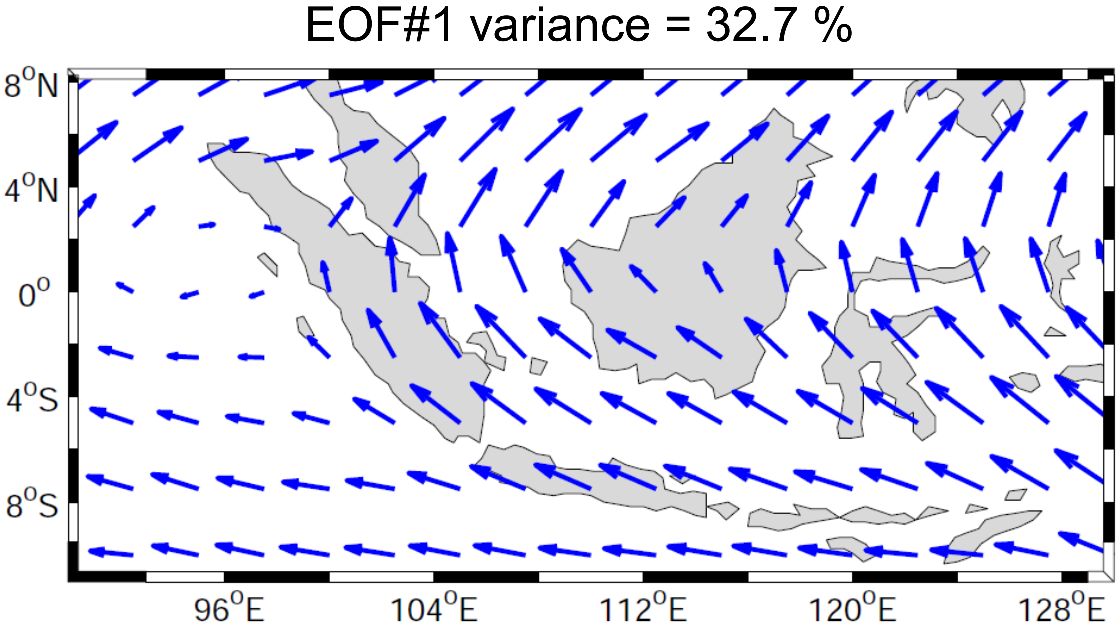
- daily GSOD observed rain-gauges, pentad CMAP, 3-hourly CMORPH rainfall

- 3-hourly 850 hPa winds from RegCM3 simulation (horizontal resolution = 25km) using NCEP II as lateral forcings

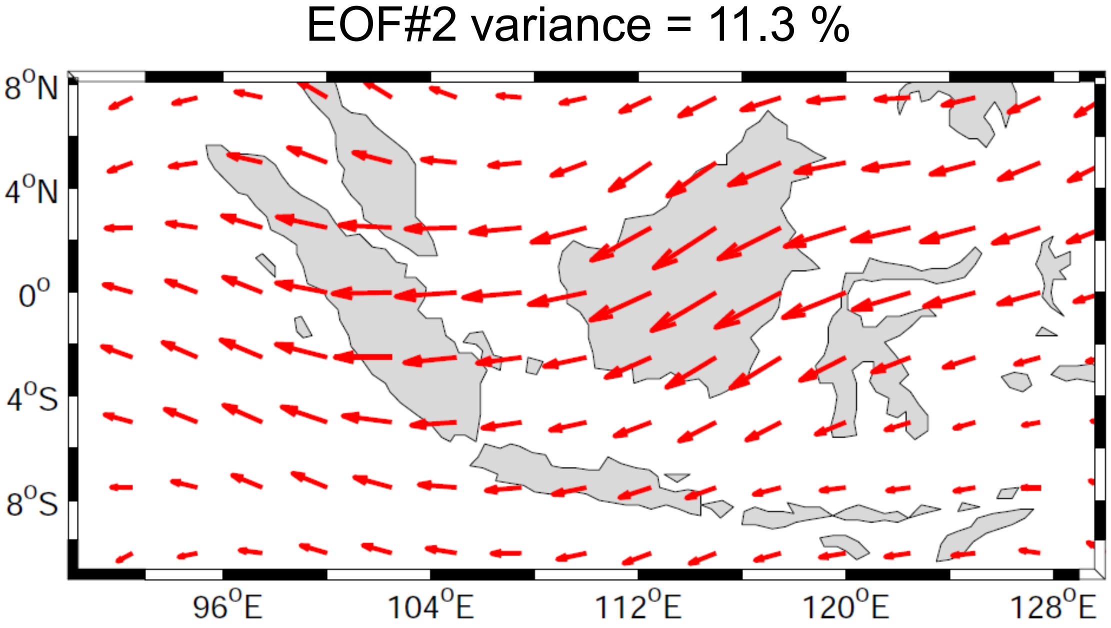
- pre-filtering using EOF of the unfiltered data (leading 9 EOFs accounting for 75 % of total variance)

- k means dynamical clustering : a 5-state solution is chosen according to « classifiability » index (that is similarity between the cluster centroids obtained from 500 simulations of the seeds ; Michelangeli et al., 1995) and as a balance between physical interpretability and statistical robustness of the clusters

Leading two EOFs of daily 850 hPa winds (incl. annual cycle)

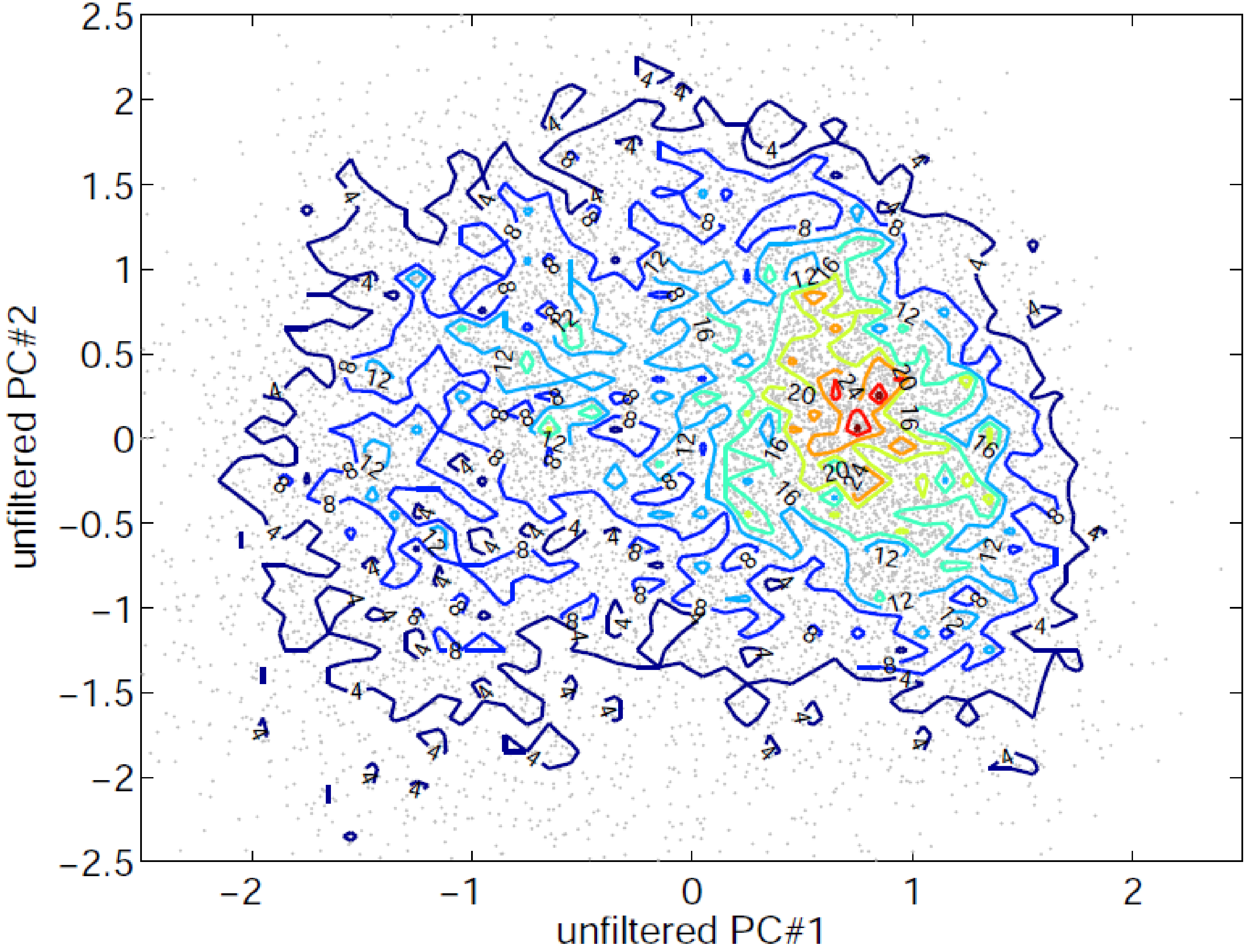


EOF#1 : ~ 90° curvature at the equator superimposed on a meridional flow = monsoon (+ during boreal summer and - during austral summer)

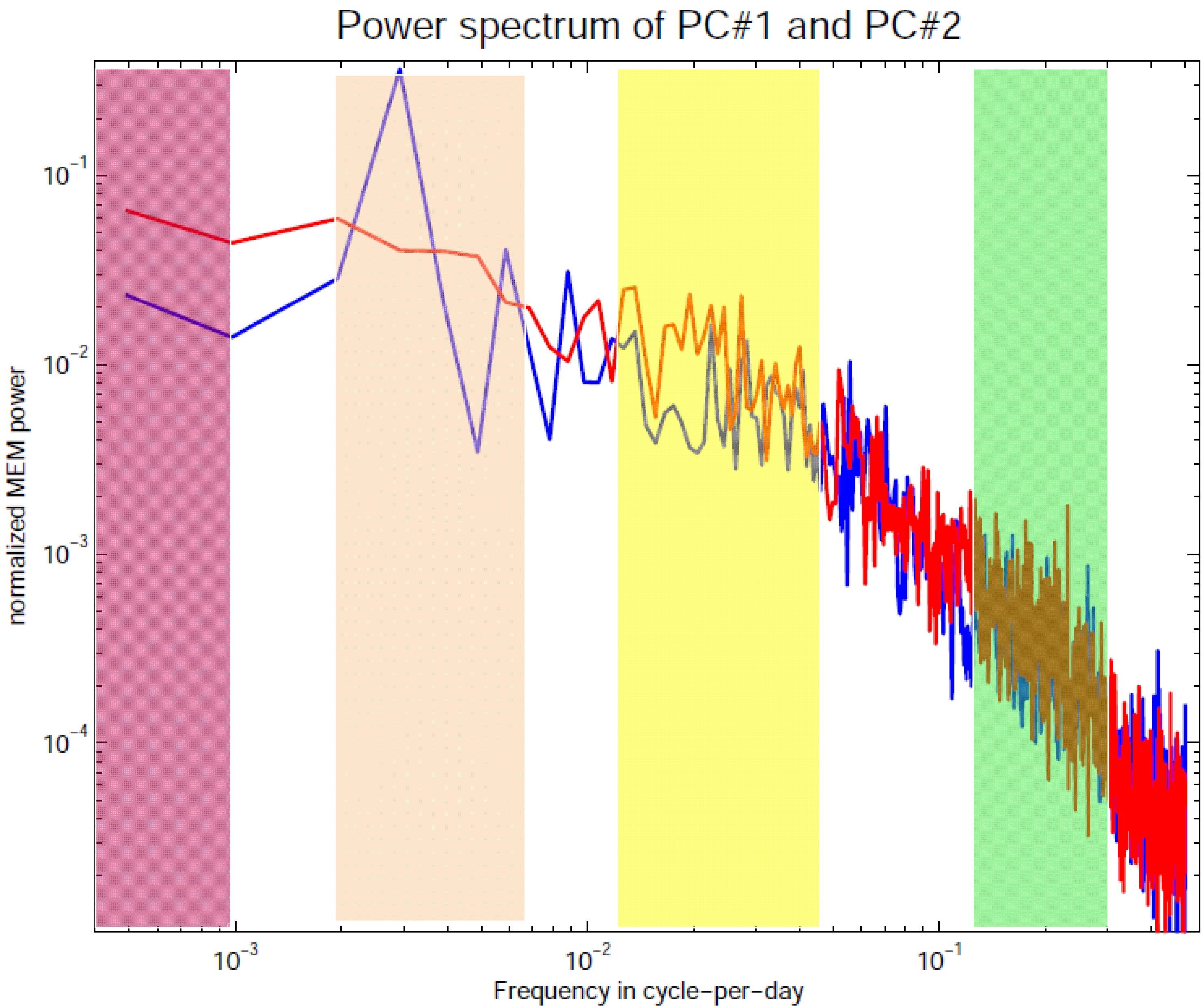


EOF#2 : ~ homogeneous zonal anomalies, stronger at the equator (+ : eastward anomalies ; - : westward anomalies)

Bi-dimensional PDF of two leading PCs

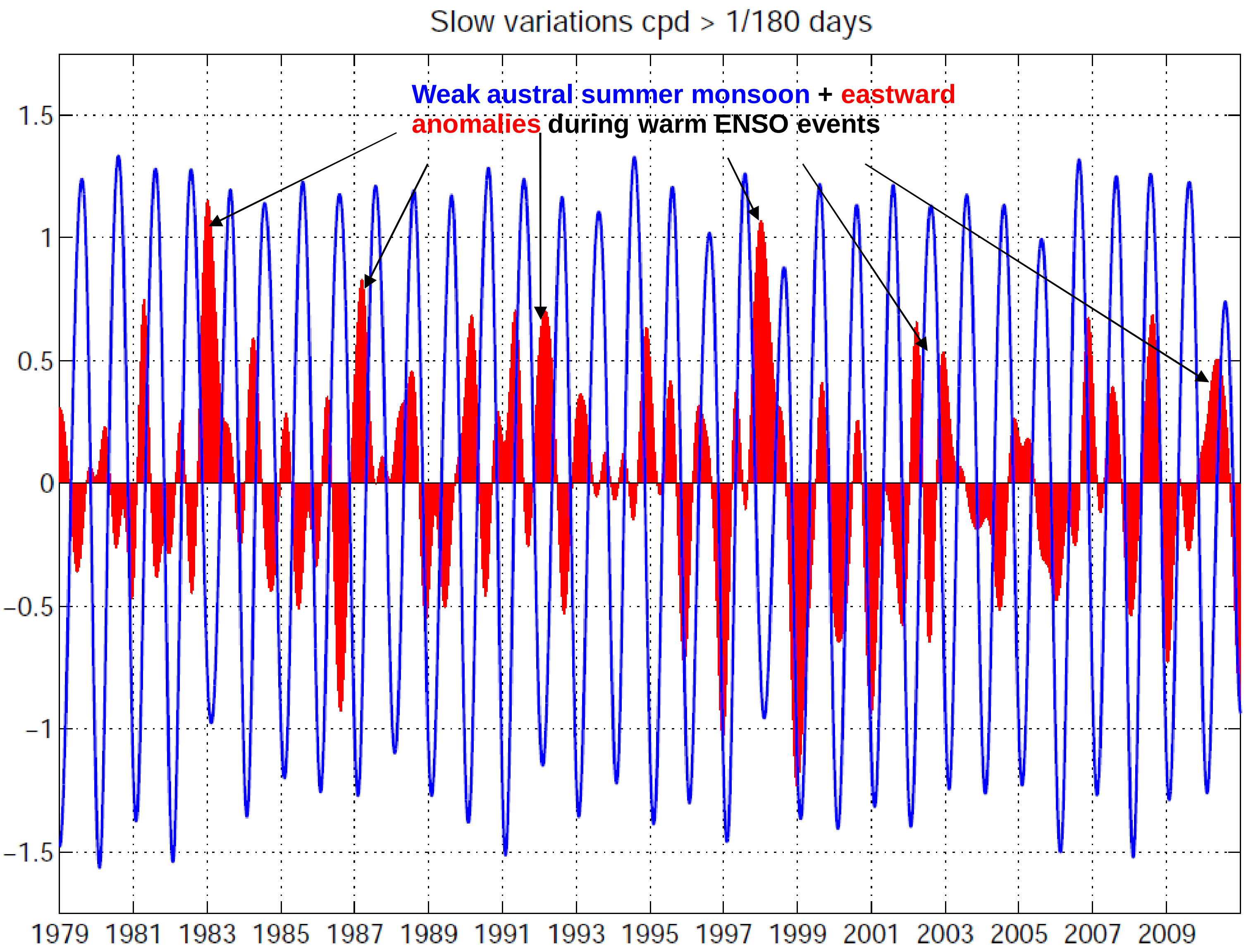


Fairly continuous and hard to detect « true » WR as maxima in the PDF



PC#1 ~ annual cycle + fast variations

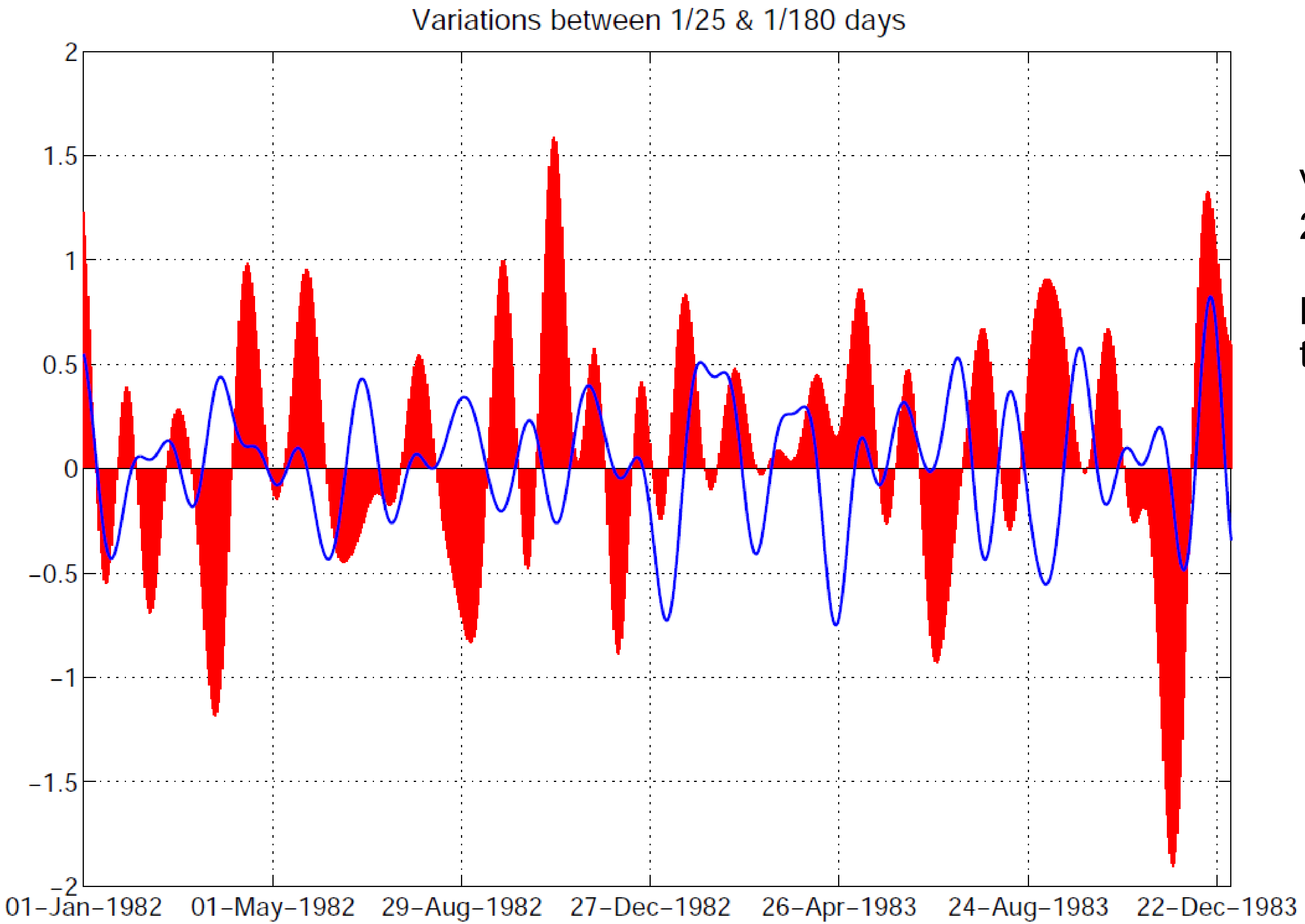
PC#2 ~ MJO + ENSO + fast variations



Variations longer than semi-annual cycle

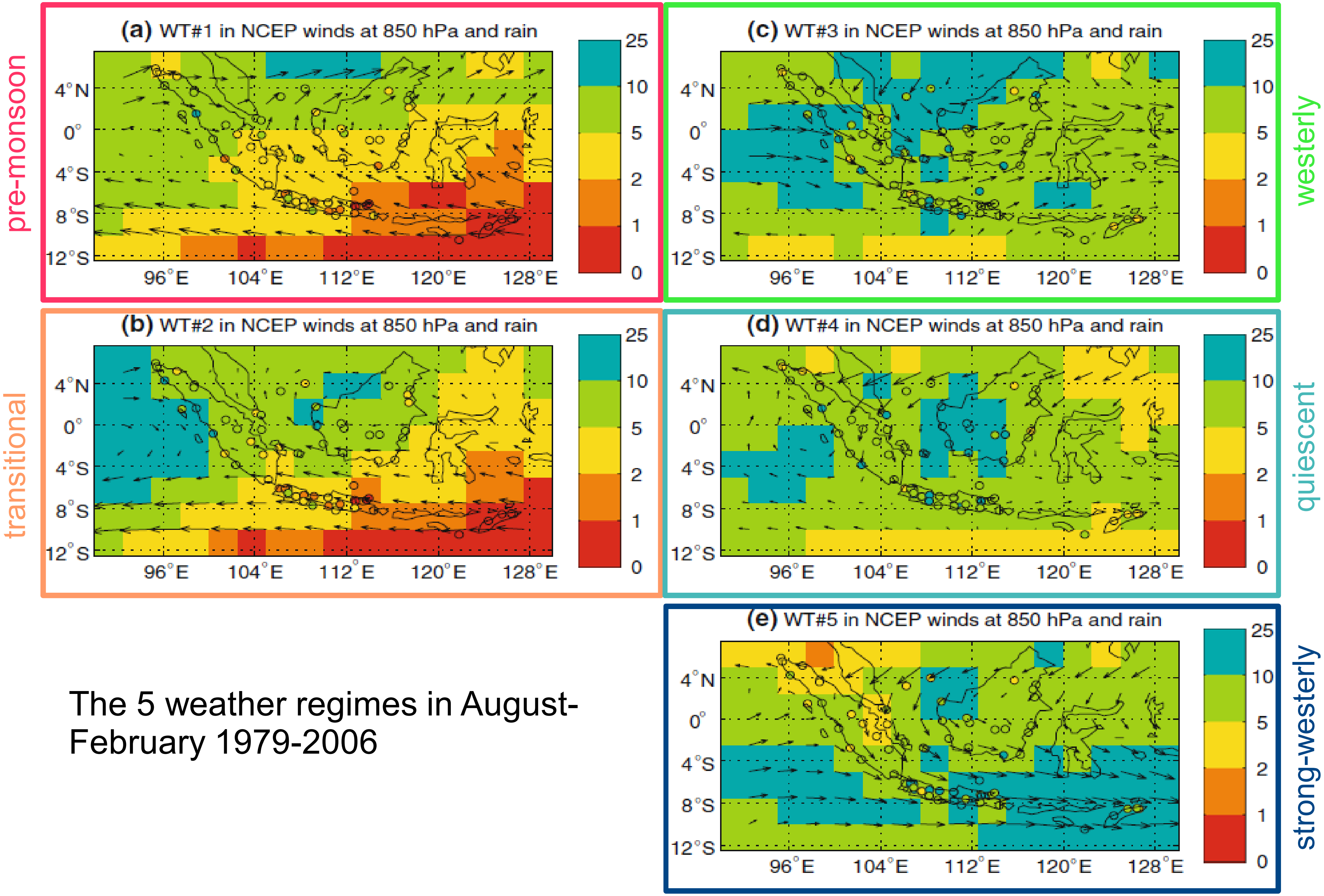
PC#1 ~ modulated annual cycle

PC#2 ~ ENSO + quasi-biennal variations



Variations between 25 and 180 days

More energy in PC#2 than in PC#1

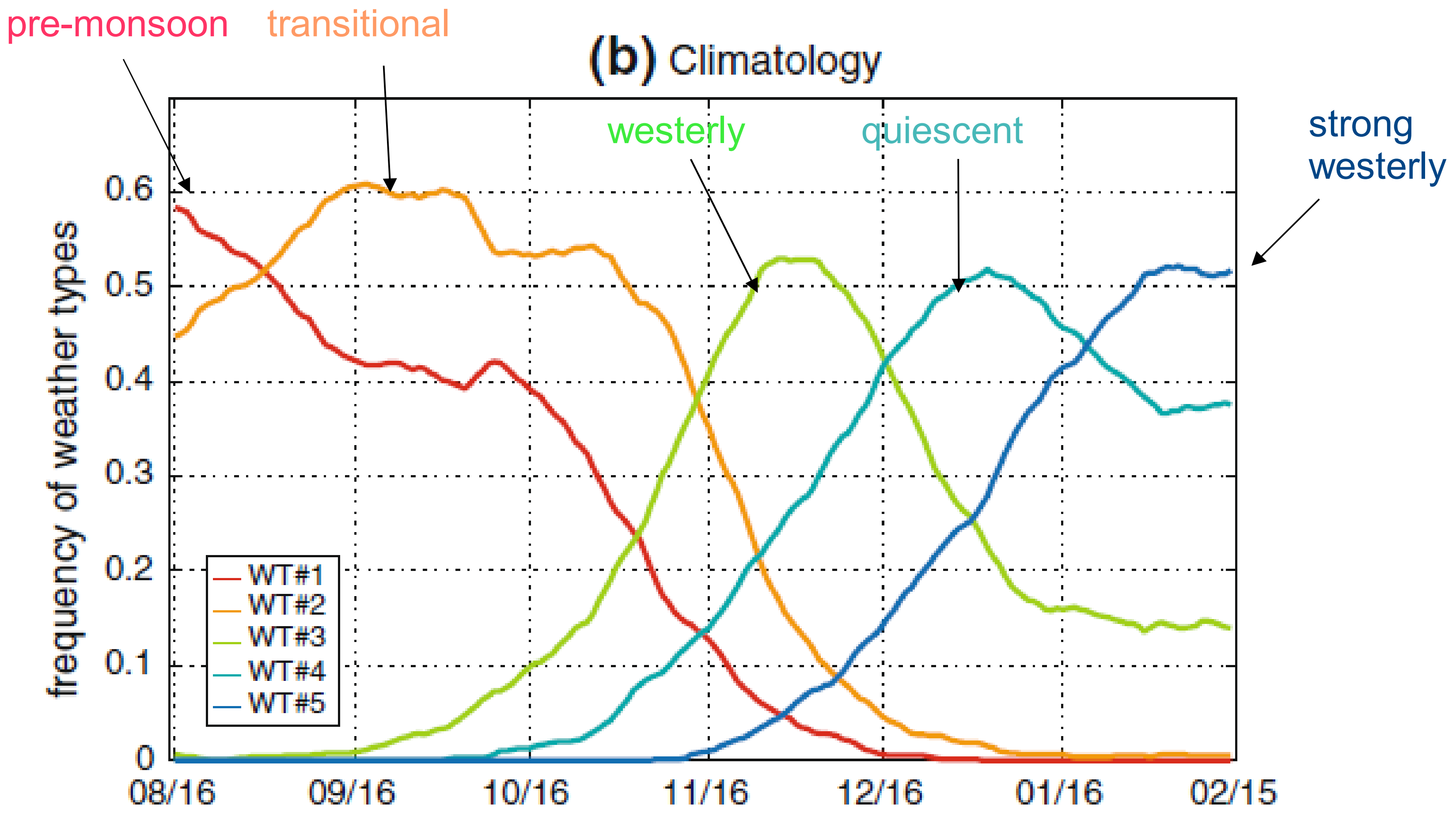


The 5 weather regimes in August-February 1979-2006

Fig. 9 Composite maps of rainfall (in mm/day) in CMAP (*shadings*) and GSOD (*filled circle*) together with reanalysis winds at 850 hPa for each weather type. The composites were constructed by averaging the respective raw fields over the days assigned to each weather type, without subtracting out the climatological mean. In the text, the five WTs are referred to respectively as "pre-monsoonal", "transitional", "westerly", "quiescent", and "strong-westerly"

(Moron et al., 2010)

WR can be firstly interpreted mostly as specific stages of the annual cycle ...



(Moron et al., 2010)

A possible decomposition of the atmospheric variation due to annual cycle and its residuals (incl. ENSO as well as MJO and faster variations)

f_j is a binary variable of the WR_i (= 1 when WR_i is observed and 0 elsewhere) for day *j*

X_j is the winds for day *j*

$\bar{X}_j = \frac{1}{28}\sum_{j=1}^{28} X_j$ is the climatological daily mean of winds

$\bar{f}_{ij} = \frac{1}{28}\sum_{j=1}^{28} f_j$ is the climatological daily frequency of each WR_i

Raw composite for WR_i

$$\overline{WR}_i = \frac{1}{\sum_{j=1}^{5936} f_j} \square \sum_{j=1}^{5936} X_j \square f_j$$

Mean seasonal component for each WR_i

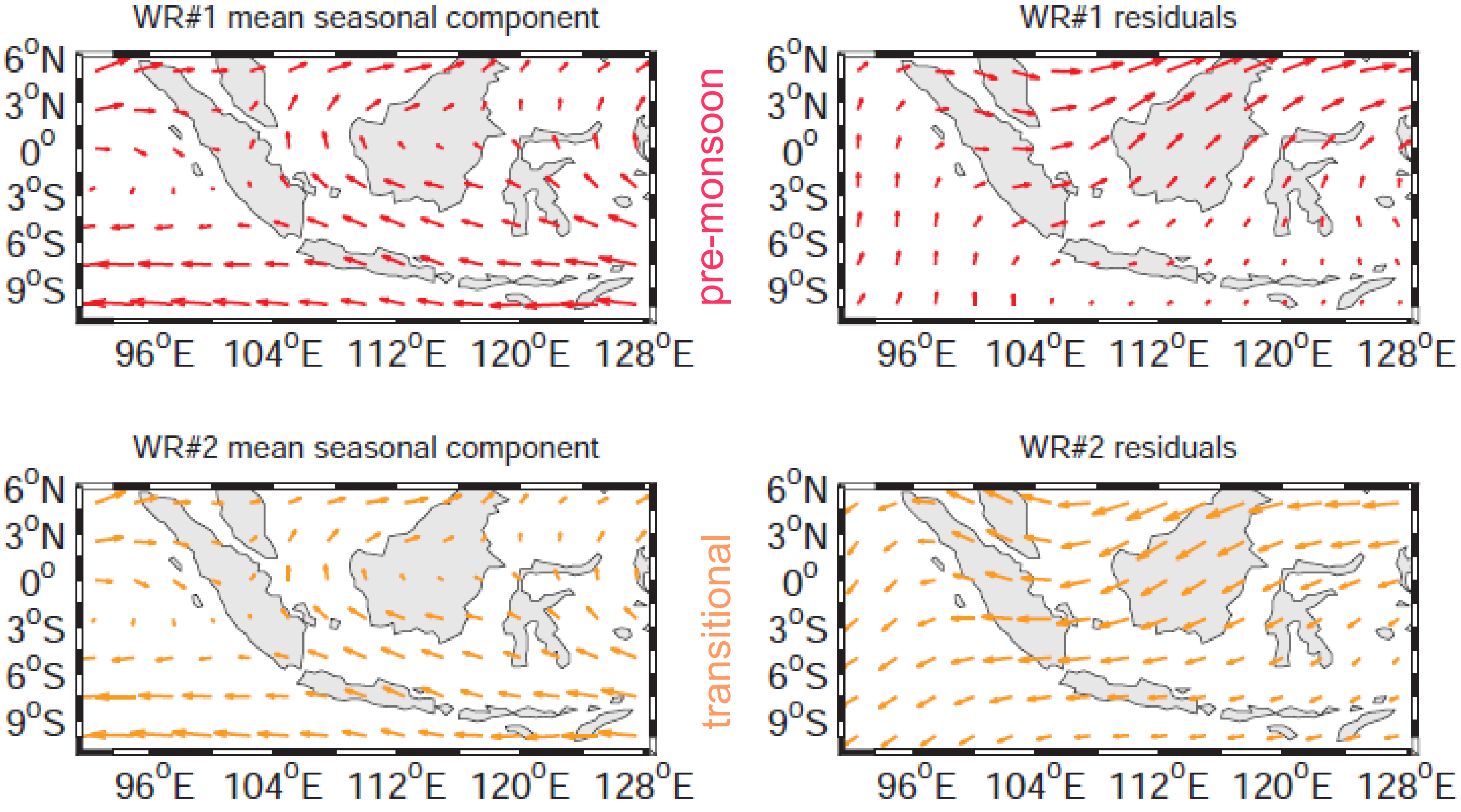
$$\overline{WR}_i^{SC} = \frac{1}{\sum_{j=1}^{212} \bar{f}_{ij}} \square \sum_{j=1}^{212} \bar{X}_j \square \bar{f}_{ij}$$

Residuals including ENSO and fast variations for each WR_i

$$\overline{WR}_i^{Res} = \overline{WR}_i - \overline{WR}_i^{SC}$$

Decomposition of WR into a mean seasonal component and a residual (1) ...

Before austral summer monsoon



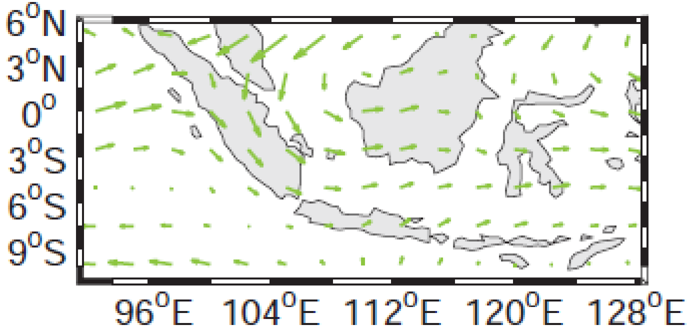
Stronger WSW monsoon north of 0°

Easterly anomalies = delayed onset of the austral summer monsoon

Decomposition of WR into a mean seasonal component and a residual (2) ...

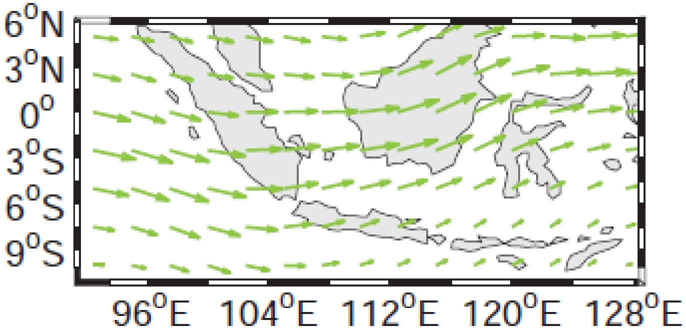
Start of the austral summer monsoon

WR#3 mean seasonal component



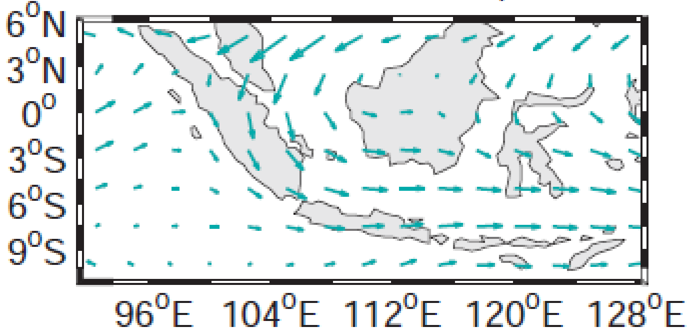
westerly

WR#3 residuals



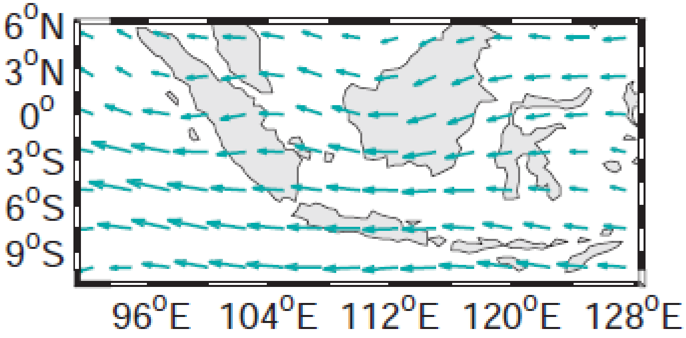
W anomalies = early onset across Monsoonal Indonesia

WR#4 mean seasonal component



quiescent

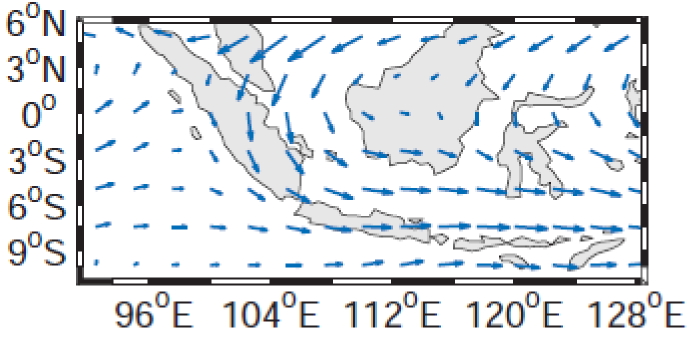
WR#4 residuals



E anomalies = weak austral summer monsoon

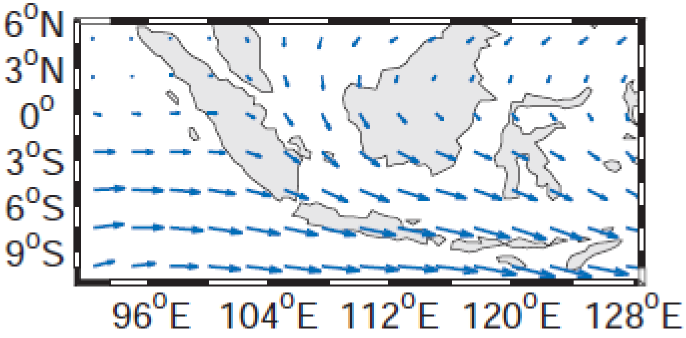
Core of the austral summer monsoon

WR#5 mean seasonal component



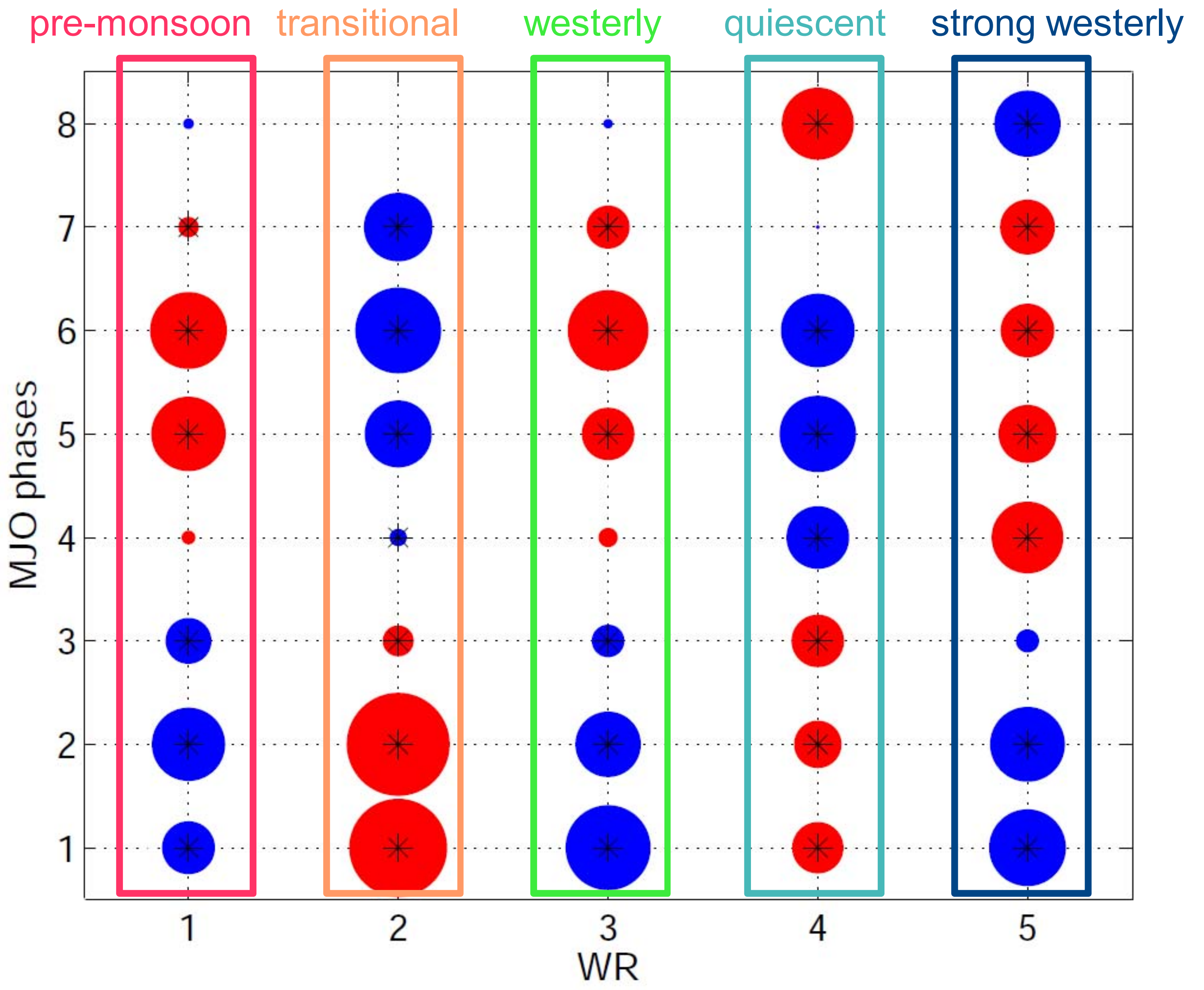
strong-westerly

WR#5 residuals

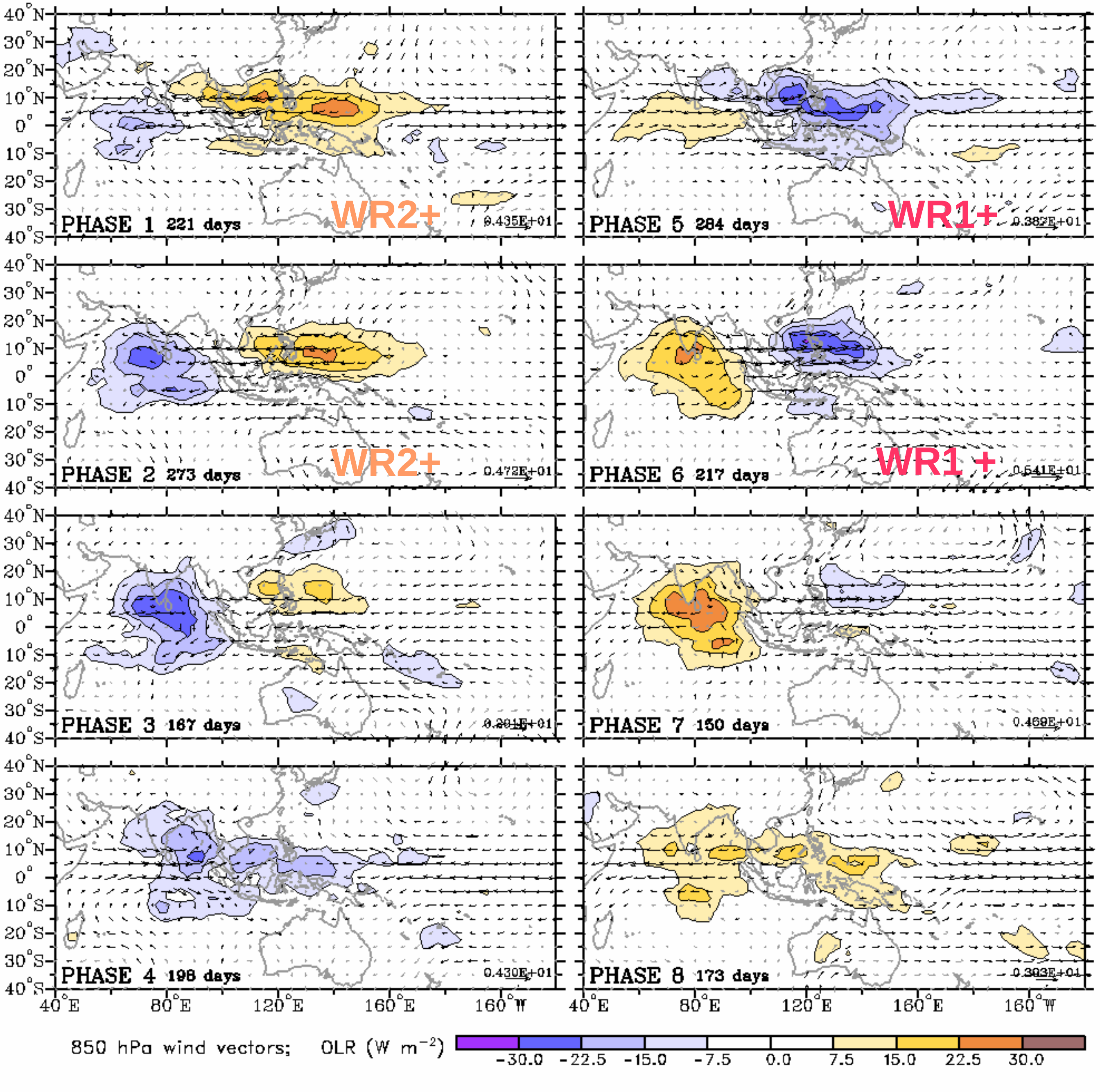


WNW anomalies S of 0° = strong austral summer monsoon

Frequency of WR by MJO phases (observed – expected frequencies)

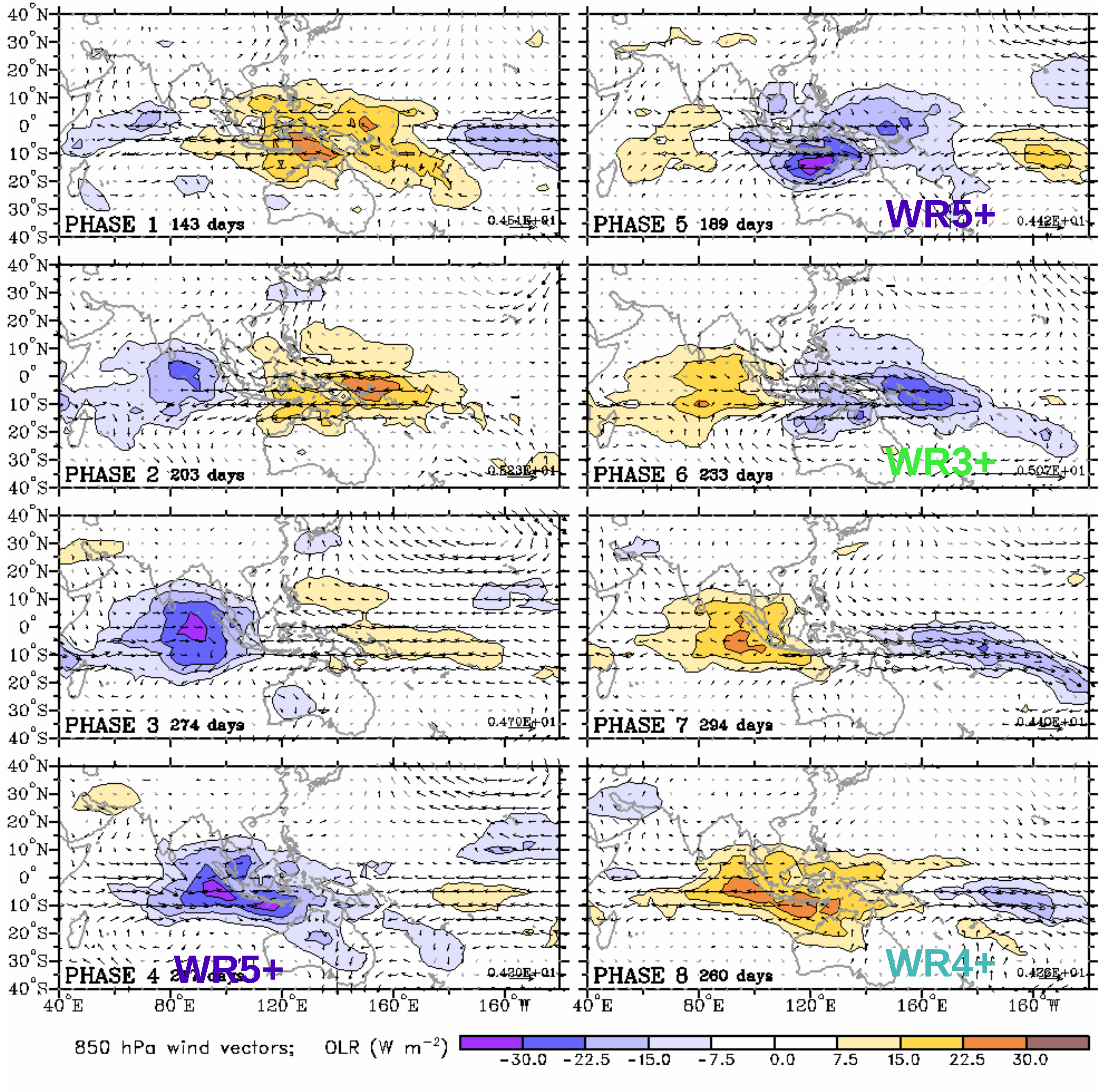


* : significantly more likely than expected by chance (at 99 % level)
red dot = more likely than expected and blue dot = less likely than expected



OLR and 850 hPa wind anomalies associated with 8 phases of MJO in Sept.-Nov.

(Wheeler and Hendon, 2004)



OLR and 850 hPa wind anomalies associated with 8 phases of MJO in Dec.-Feb.

(Wheeler and Hendon, 2004)

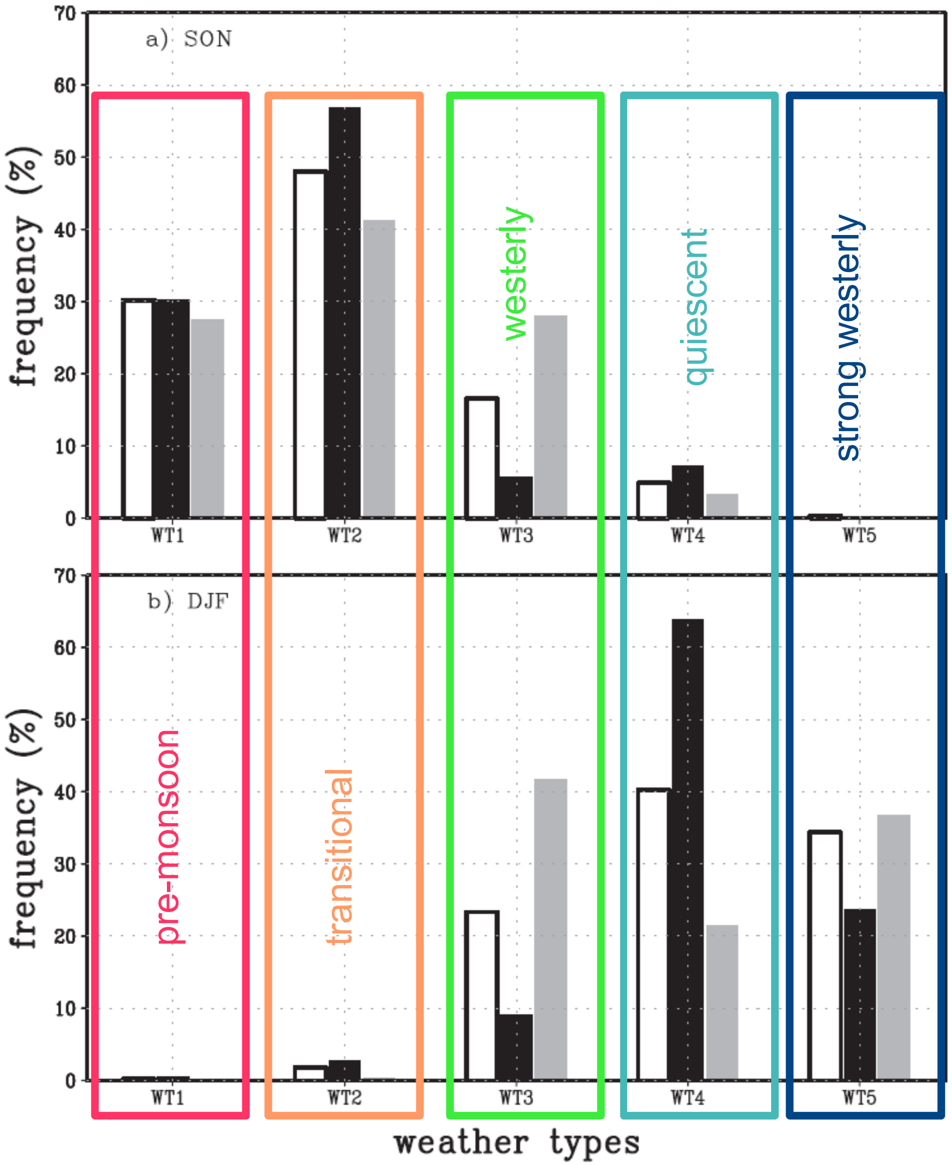
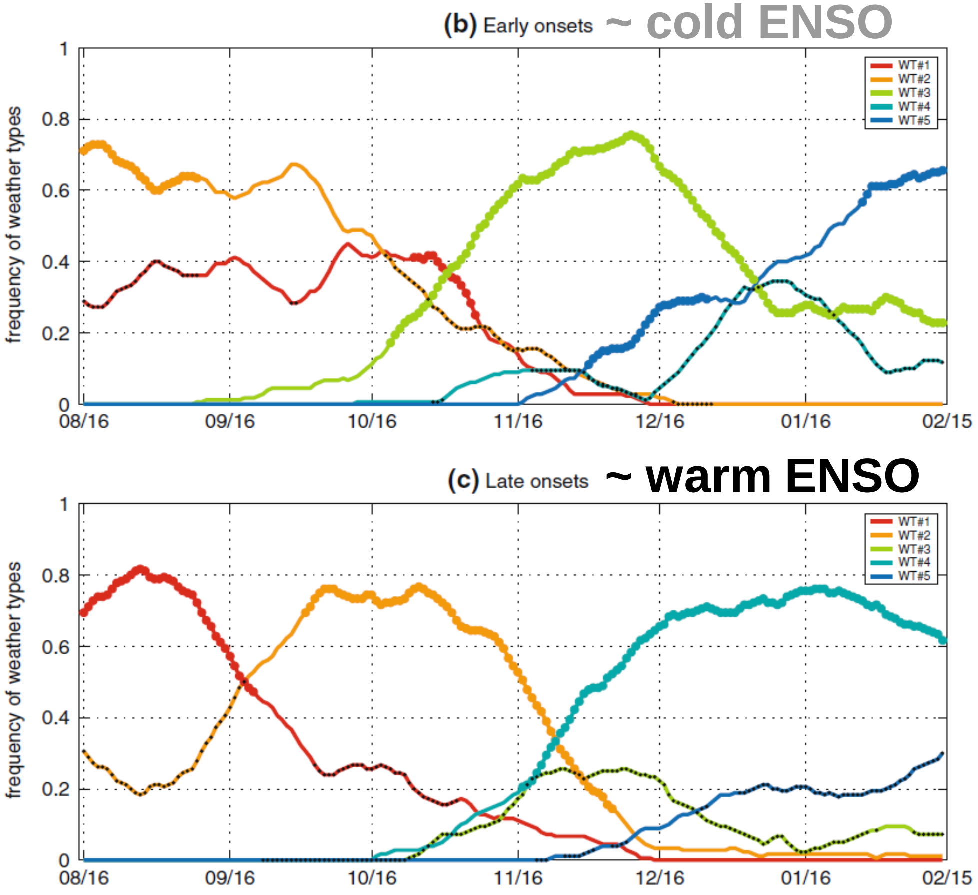


FIG. 9. Frequencies of WT1–WT5 during all years (white), El Niño years (black), and La Niña years (gray) during (a) SON and (b) DJF.

(Qian et al., 2010)



(Moron et al., 2010)

Warm ENSO forces low-level easterly anomalies west of large-scale subsidence over the warm pool, so more WR2 and WR4 and less WR3 an WR5 (and conversely for cold ENSO)

So weather regimes could be interpreted either as ...

- *specific phases of the* ***climatological annual cycle***

$$\text{WR1} \longrightarrow \text{WR2} \longrightarrow \text{WR3} \longrightarrow \text{WR4} \longrightarrow \text{WR5}$$

before the monsoon ... onset ... core of the austral monsoon

- *... and/or snapshots of the* ***MJO cycle***

$$1 \longrightarrow 2 \longrightarrow 3 \longrightarrow 4 \longrightarrow 5 \longrightarrow 6 \longrightarrow 7 \longrightarrow 8$$

WR2 and WR4 are favored during easterly phase of MJO over Maritime Continent

WR1, WR3 and WR5 are favored during westerly phase of MJO over MC

- *... and/or seasonally-consistent anomalies related to* ***ENSO events***

Warm ENSO (easterly ano. + large-scale subsidence) favors mostly WR2 and WR4

Cold ENSO (westerly ano. + large-scale ascendance) favors mostly WR3 and WR5

- a last periodic signal is related to diurnal cycle ...

NOVEMBER 2010 QIAN ET AL. 3521

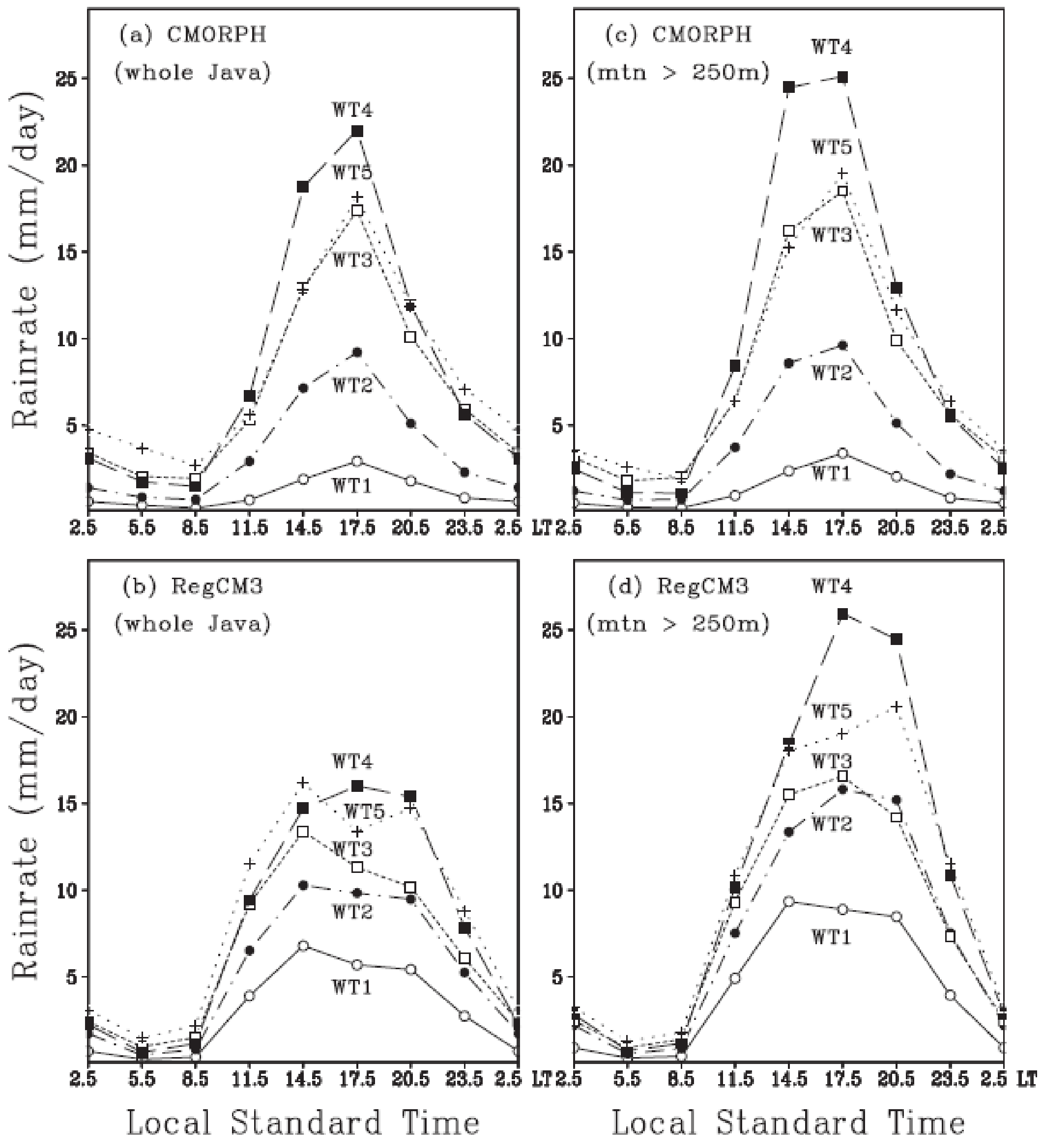
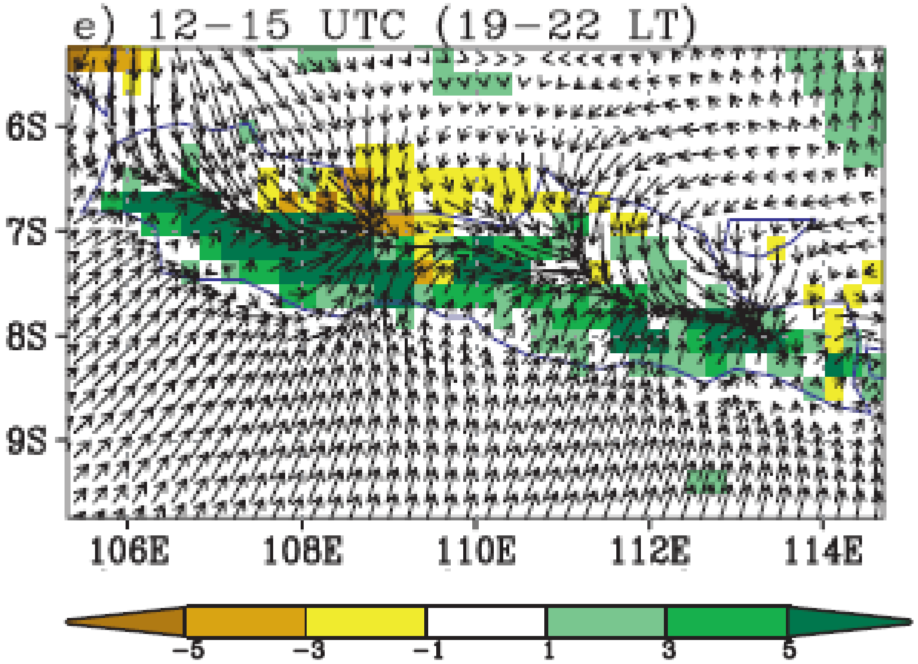


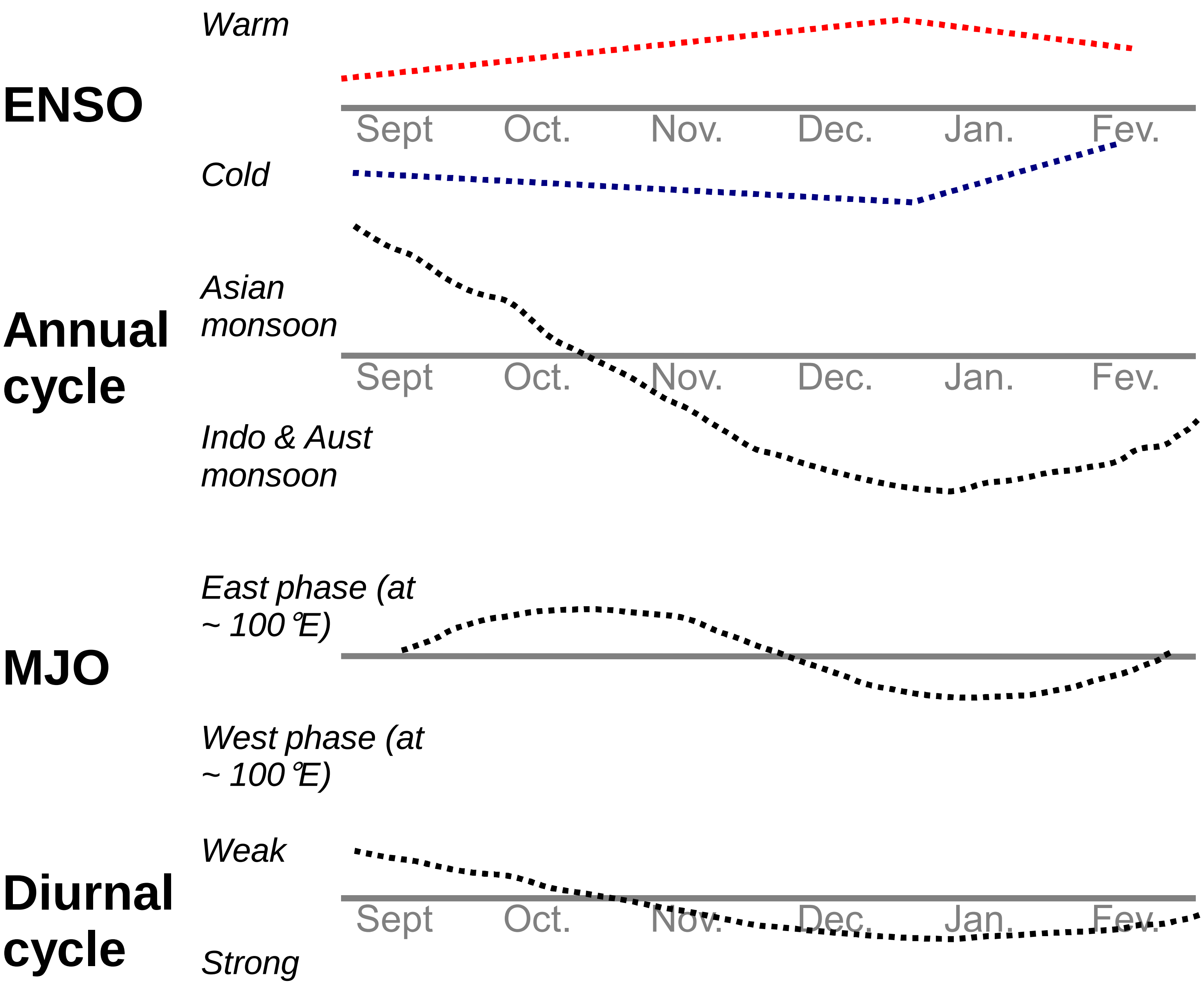
FIG. 10. Diurnal cycles of the CMORPH and RegCM3 rainfall (mm day^{-1}) (a),(b) over the whole Java Island and (c),(d) over mountainous regions (terrain elevation higher than 250 m) for WT1 (solid), WT2 (dot–dashed), WT3 (short dashed), WT4 (long dashed), and WT5 (dotted). "LT" denotes the local standard time at Jakarta, Indonesia.

(Qian et al., 2010)

Snapshot of the warm ENSO – climatology composite of low level winds + rainfall (mm/day) near the peak of diurnal cycle in DJF in RegCM3



- diurnal cycle is stronger during wet season for quiescent WR4
- warm ENSO, through anomalous easterlies, increases the prevalence of WR4, thus increasing locally the rainfall through enhanced sea breeze effects and interaction with topography



Easterly anomalies in low-levels + large-scale subsidence across Maritime Continent during warm ENSO events (peak around DJ)

Transition between SE and NW low-level winds south of the equator. This signal is the largest in amplitude

Alternance between westerly (+ enhanced convection) and easterly anomalies (+ suppressed convection) across Maritime Continent without clear phase locking to the annual cycle

Stronger during wet season & quiescent regional-scale conditions

WRs integrate all these processes which interact probably in a non-linear way

Concluding remarks

- WR applied to **unfiltered daily data** as a tool to analyze the continuum of temporal scales at regional-scale

- Smallest features and those which occur randomly in space (as Tropical Depression) are filtered out by the EOF and k-means

- the emphasized regional-scale features are the most recurrent as in theoretical approach BUT they should be better interpreted as **snapshots of periodic/quasi-periodic variations** rather than « *true* » dynamical regimes

- WR offer a **comprehensive view** and provides some insights about scale interaction **without the need of scale separation** and also about temporal & spatial modulation of the predictable scales (i.e. before the onset of austral summer monsoon, the ENSO anomaly is added to the basic state while thenafter, it is substracted from the basic state, thus warming local SST and enhancing quiescent WR4 and the diurnal cycle and breezes, which fragment the regional-scale seasonal rainfall anomalies, and made them less predictable)

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