Roles in Climate of Tropical Convection and its Multiscale Organization

YOTC International Science Symposium & 8th AMY Workshop

16-19, May Beijing, China

Guoxiong WU

LASG, Institute of Atmospheric Physics,

Chinese Academy of Sciences Beijing, China

Outlines

1. Brief Review
2. LFV/ISO and Asian Summer Monsoon Onset
3. Tropical Vortex and BOB Monsoon Onset
4. Inertial Instability, ITCZ and SAM Onset
5. Monsoon, Subtropical Anticyclone and Tropical ISO
6. Intraseasonal modulation of tropical cyclogenesis
7. Extratropical Climate Impacts of Tropical Cyclone
8. Needs from the YOTC/AMY studies

Monsoon and
the Year of Tropical Convection

-WCRP JSC-XXVIII

Guoxiong WU, Richard Lawford and Howard Cattle

27 March, 2007 Zanzibar

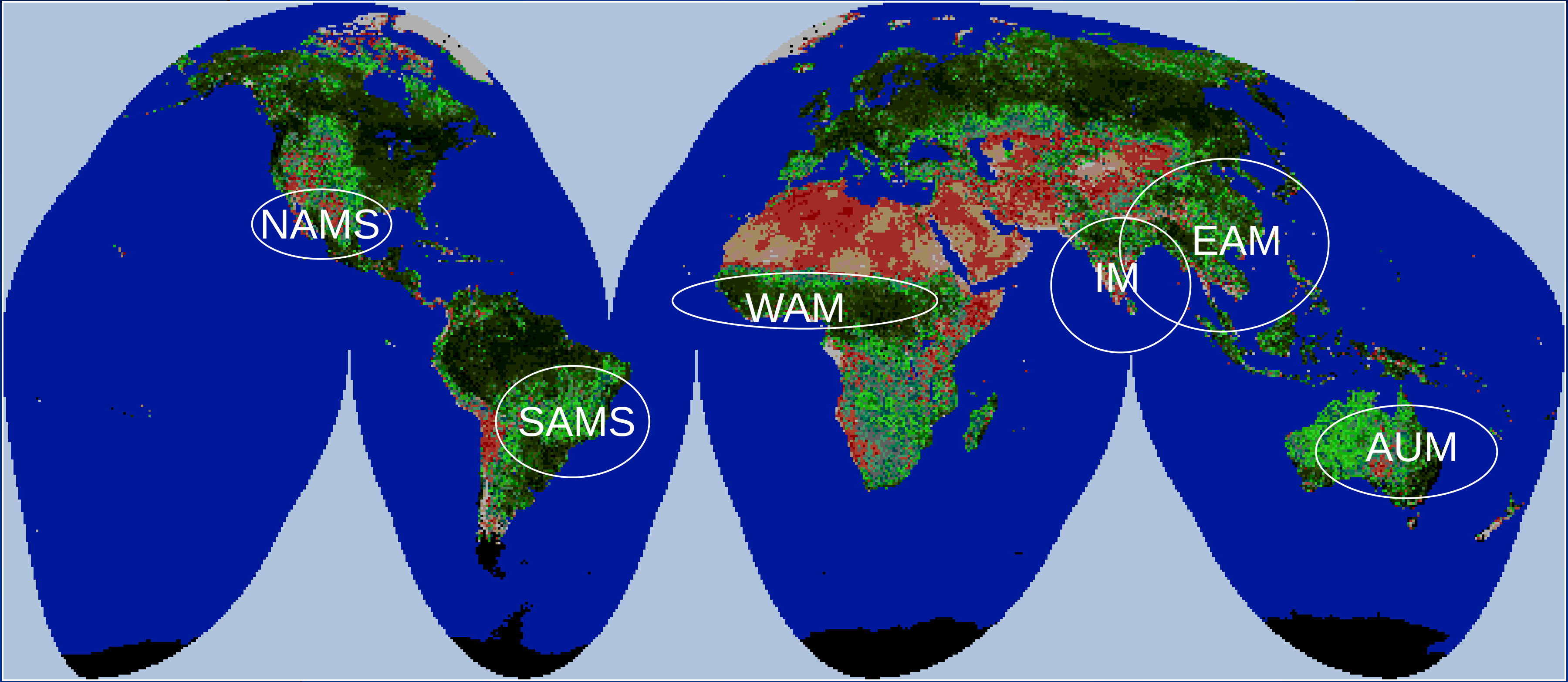
1. Science Significance

Monsoon- one of the central components of the climate system:

- **influence the global climate system**
- **has distinct regional characteristics**

Monsoonal circulations dominate south and east Asia and are also significant in Africa and the Americas.

Major monsoons systems of the world



2.1 WCRP Monsoon Activities

Organization and governance of WCRP

	Asia	Africa	N. America	S. America
CLIVAR SSG's cross-cutting	AAMP	VACS (AMMA)	VAMOS (NAME,MESA,VOCALS)	
GEWEX SSG's cross-cutting	CEOP/CIMS coordinating global scale and each of the Regional Hydroclimate Projects (RHPs) providing input along with GMPP and GRP			
CLiC	role of the snow/ice cover of the Tibetan Plateau, role of the cold Asian continent in the Asian winter monsoon.			

Monsoon Studies launched by WCRP

	Asia	Africa	N. America	S. America
CLIVAR	SCSMEX*	AMMA WAM	NAME/ VOCALS	MESA
GEWEX CSE's	GAME	CATCH	GAPP	LBA
	*launched by WMO/ TMRP			

2.2 YoTC

A key overarching issue for monsoon prediction is the fundamental need for improved representation of tropical convection.

WCRP WMO THORPEX A World Weather Research Programme

A Joint WCRP/THORPEX Proposed Activity

Year of Tropical Convection (YOTC)

Year of Coordinated Observing, Modeling and Forecasting:

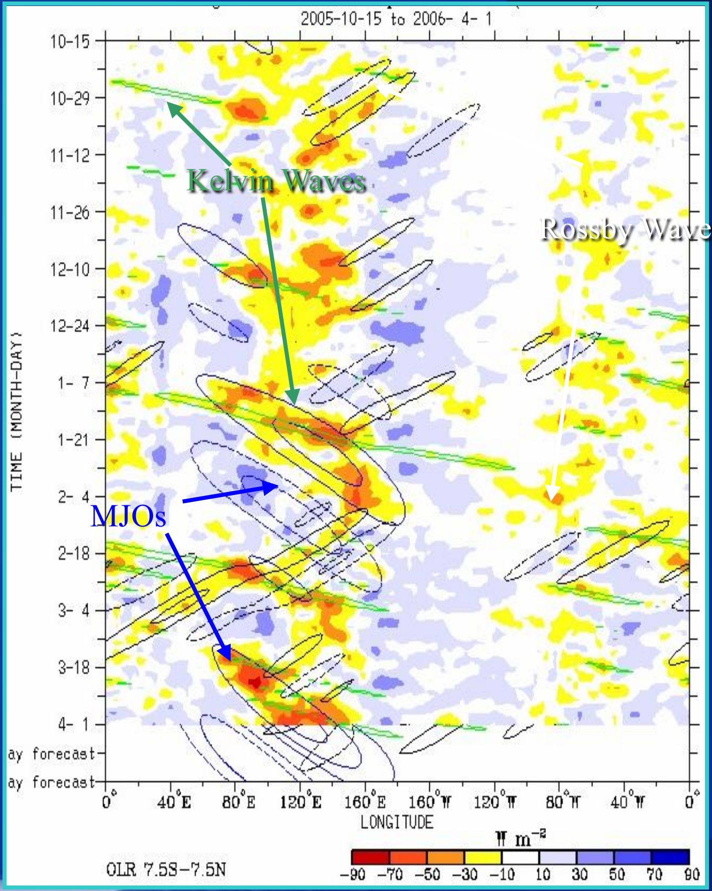
Addressing the Challenge of Organized Tropical Convection

This proposal arose from a recommendation from the THORPEX/WCRP/ICTP Workshop on Organization and Maintenance of Tropical Convection and the MJO, held in Trieste in March 2006. If implemented in 2008, this initiative would be a WCRP/THORPEX contribution to the UN Year of Planet Earth.

Our shortcomings in tropical convection severely limit the representation of key physics in weather & climate models

- **Diurnal cycle** - strongest "forced" signal in the climate system.
- Synoptic waves and **easterly waves**, including development & evolution of **hurricanes and Tropical cyclones**
- **Madden-Julian Oscillation (MJO)** and other large-scale convectively-coupled waves
- **monsoon variability**, including onset and break activity.
- **Tropical mean state**, including **ITCZ** and distributions of rainfall over oceans & continents

Winter 2005-6



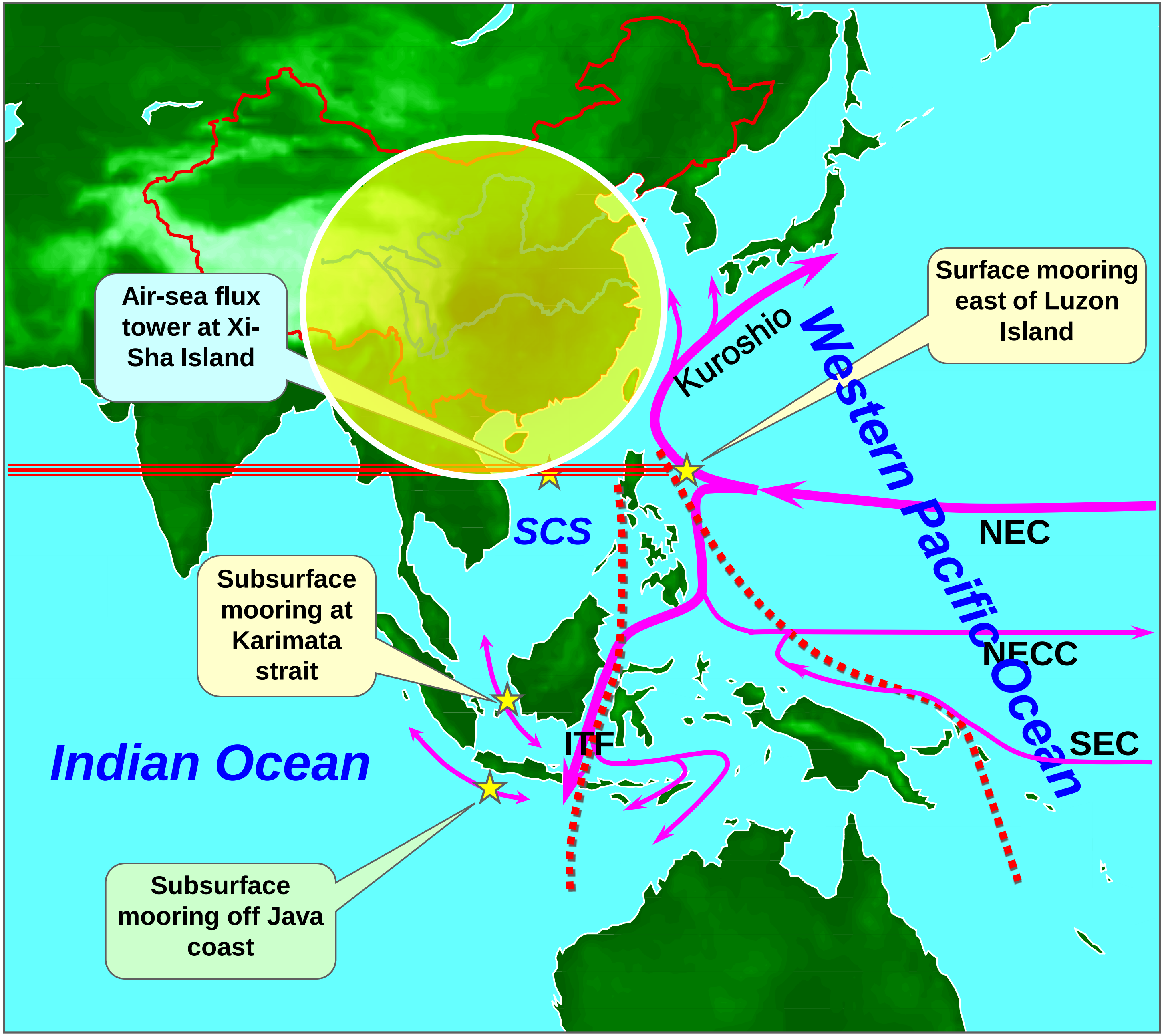
Dominant Convectively-Coupled Tropical Waves Projected onto OLR Anomalies. Wheeler and Weickmann, 2001

3. Emerging activities in the AA Monsoon region

"Asian Monsoon Year (AMY'08)":

The "Asian Monsoon Year (AMY08)" (2008-2009) initiative is a coordinated observation and modeling efforts on understanding the aerosol-cloud/radiation--hydrology cycle-circulation interaction and ocean-land-atmosphere interaction of the Asian monsoon system, and on improving monsoon prediction.

Schematic observation plan of atmosphere-ocean interaction at the Asia-Indo-Pacific Region



4. Recommendations to the JSC

The regional perspective

strengthening coordination of Asian-Australian monsoon research:

- **set up a short term task team (one year maximum) to prepare a 5-year implementation plan for an overall integrated programme of regional monsoon research**

- **with an emphasis on the COORDINATION between other monsoon studies around the world and the YOTC and on the plans for AMY activities.**

- **co-chaired by the CLIVAR (B. Wang) and GEWEX (J. Matsumoto) with representations from the JSC, CLIVAR and GEWEX Panels and each of the component activities including YOTC and representatives. (WOAP+WMP?)**

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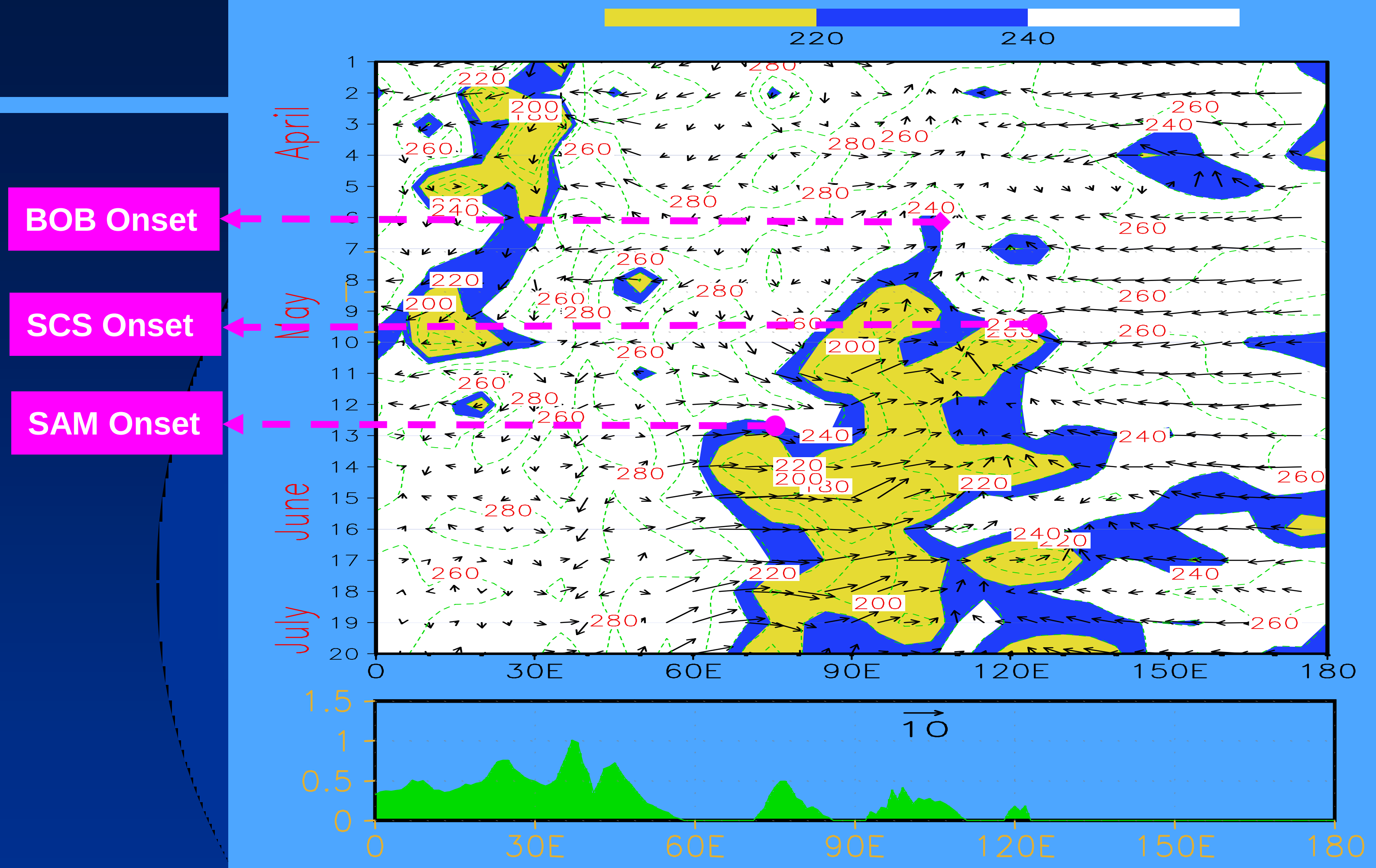
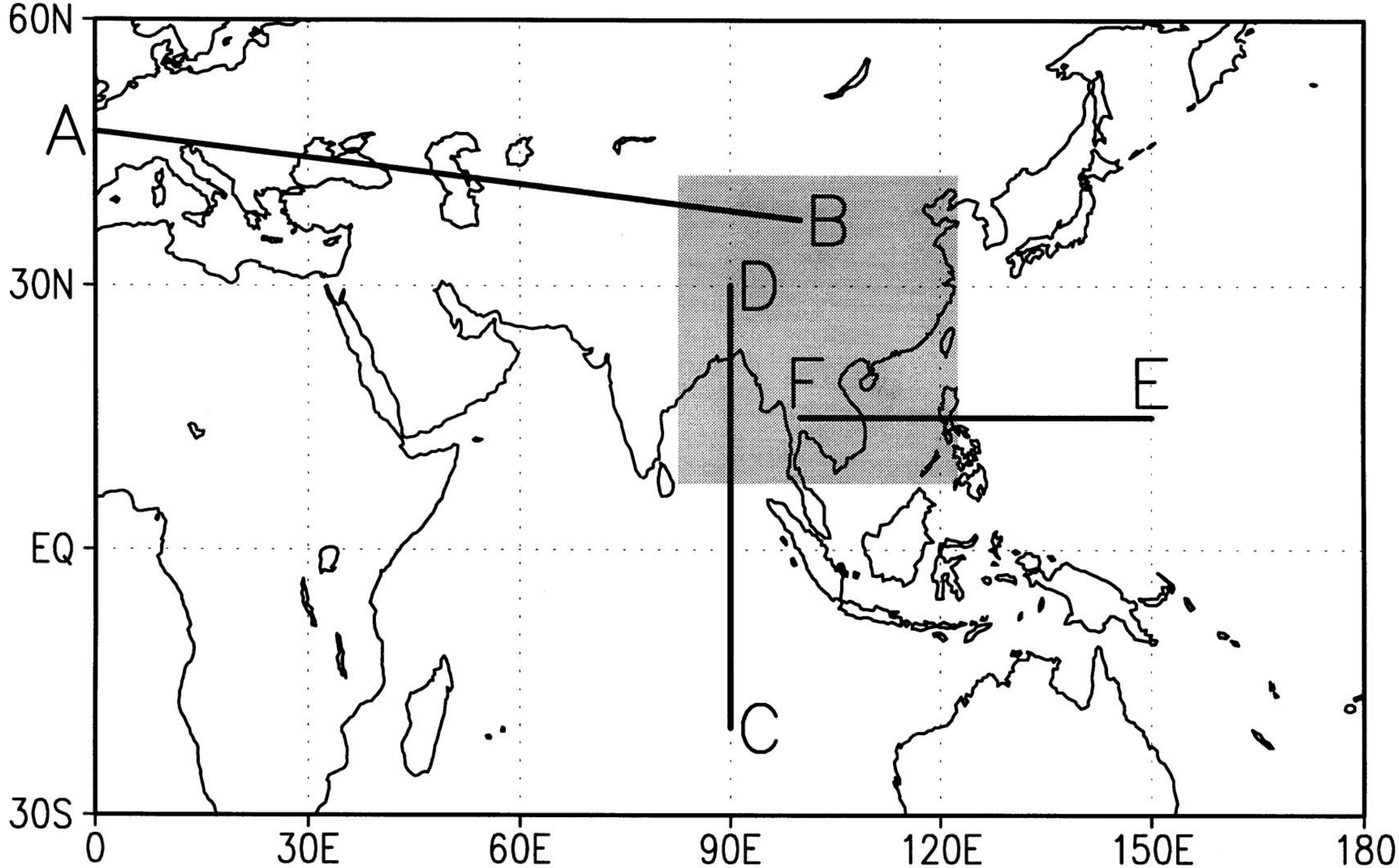
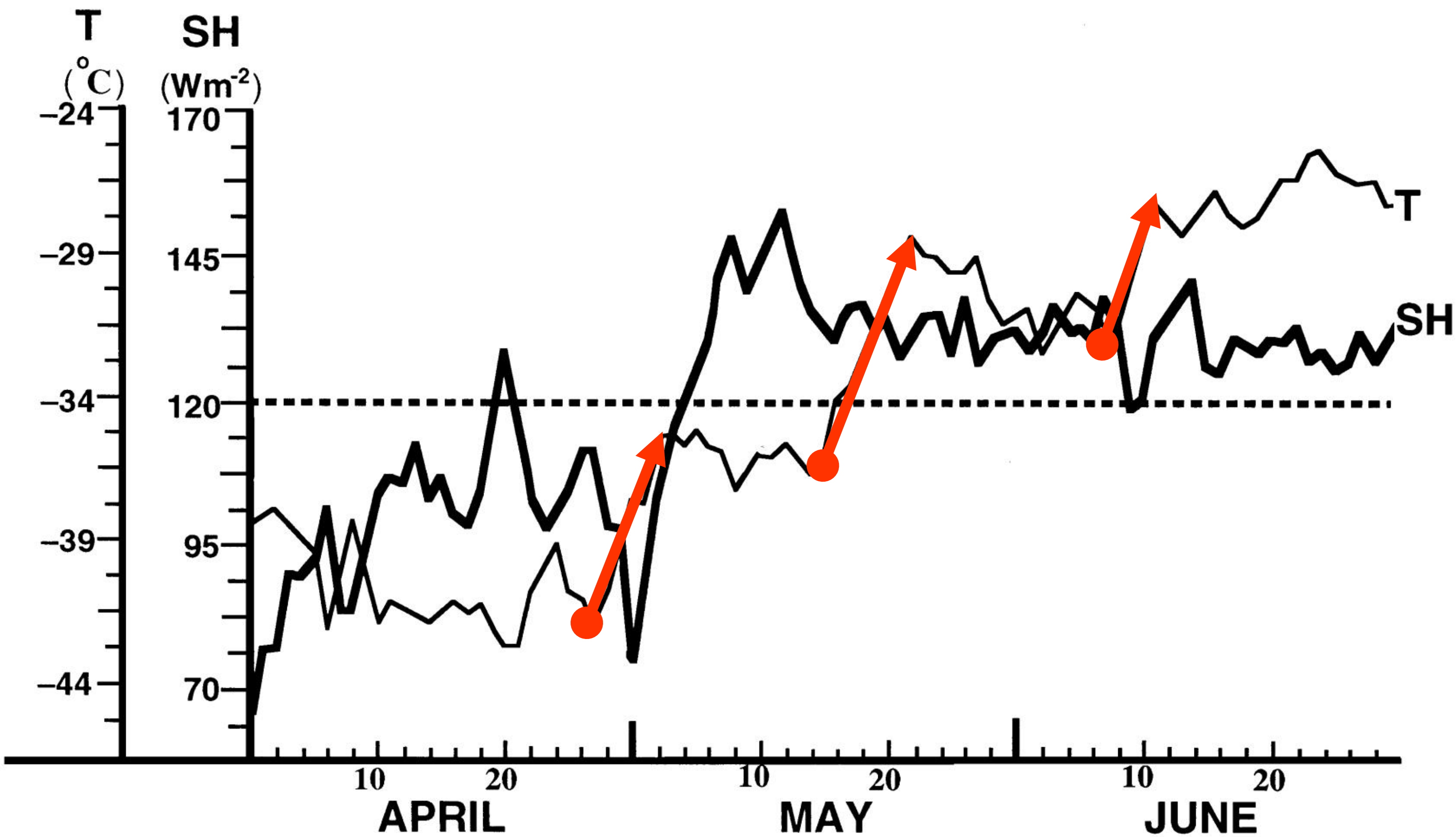
低频变化/季节内振荡
和
亚洲夏季风爆发

LFV/ISO
and
Asian Summer Monsoon Onset

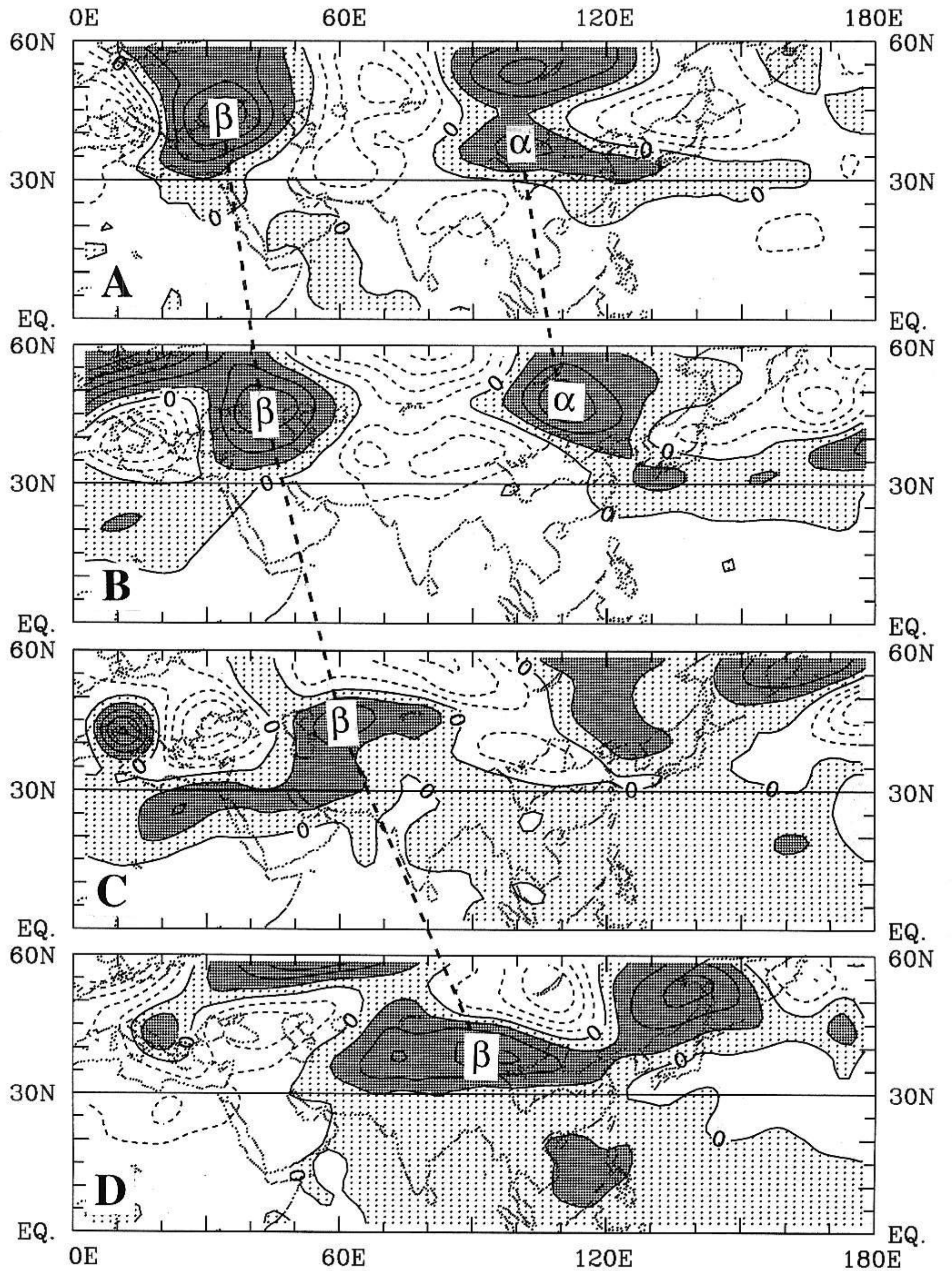


BOB Onset
SCS Onset
SAM Onset
220
240
April
May
June
July
0
30E
60E
90E
120E
150E
180
1.5
1
0.5
0
10


60N
30N
EQ
30S
0
30E
60E
90E
120E
150E
180
A
B
C
D
E
F



T
(°C)
SH
(Wm-2)
–24
–29
–34
–39
–44
170
145
120
95
70
T
SH
10
20
10
20
10
20
APRIL
MAY
JUNE


0E
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A
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α
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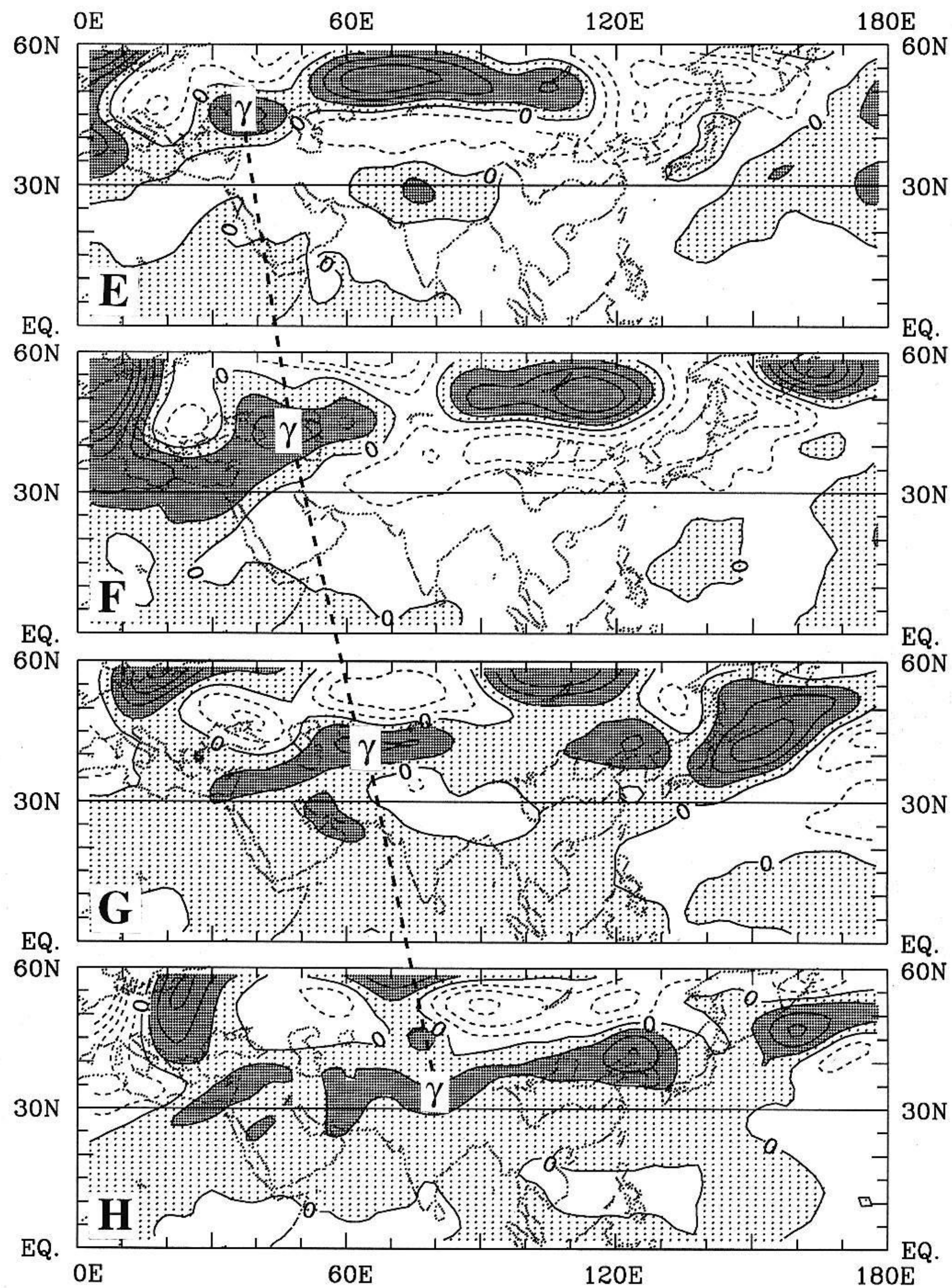
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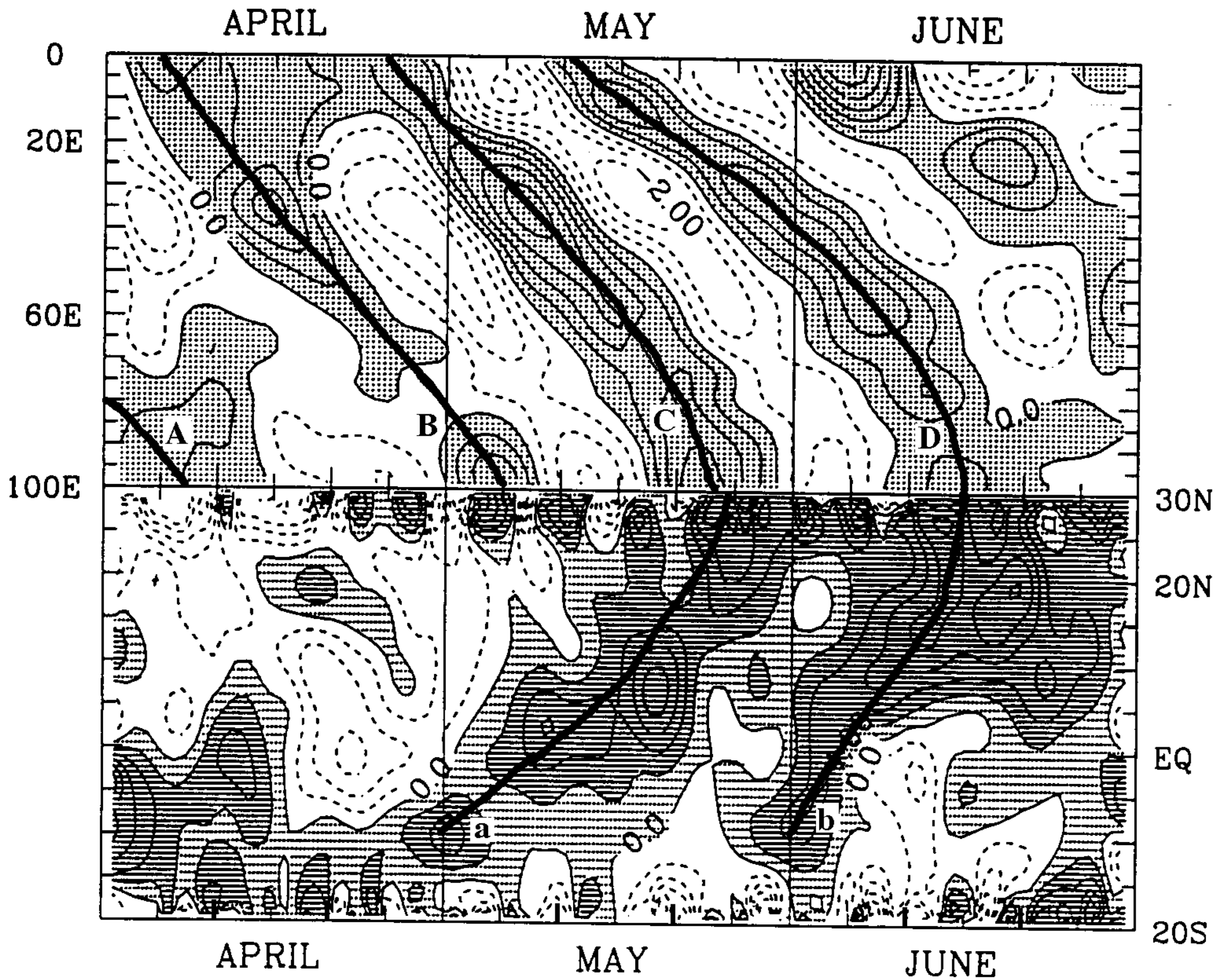
APRIL
MAY
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0
20E
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100E
30N
20N
EQ
20S
A
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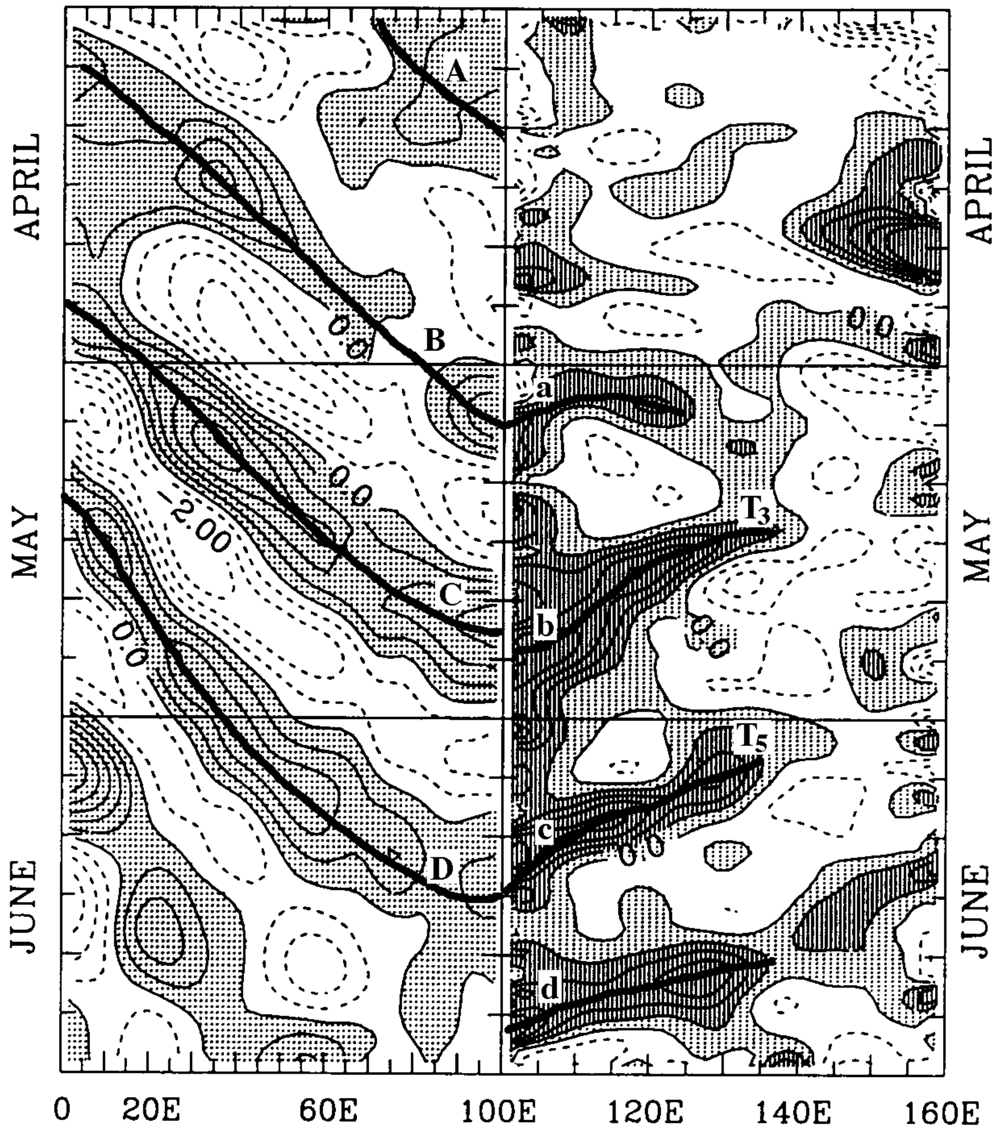
C
D
a
b
0.0
-2.00
APRIL
MAY
JUNE



Three tropical Cyclones moved westward!

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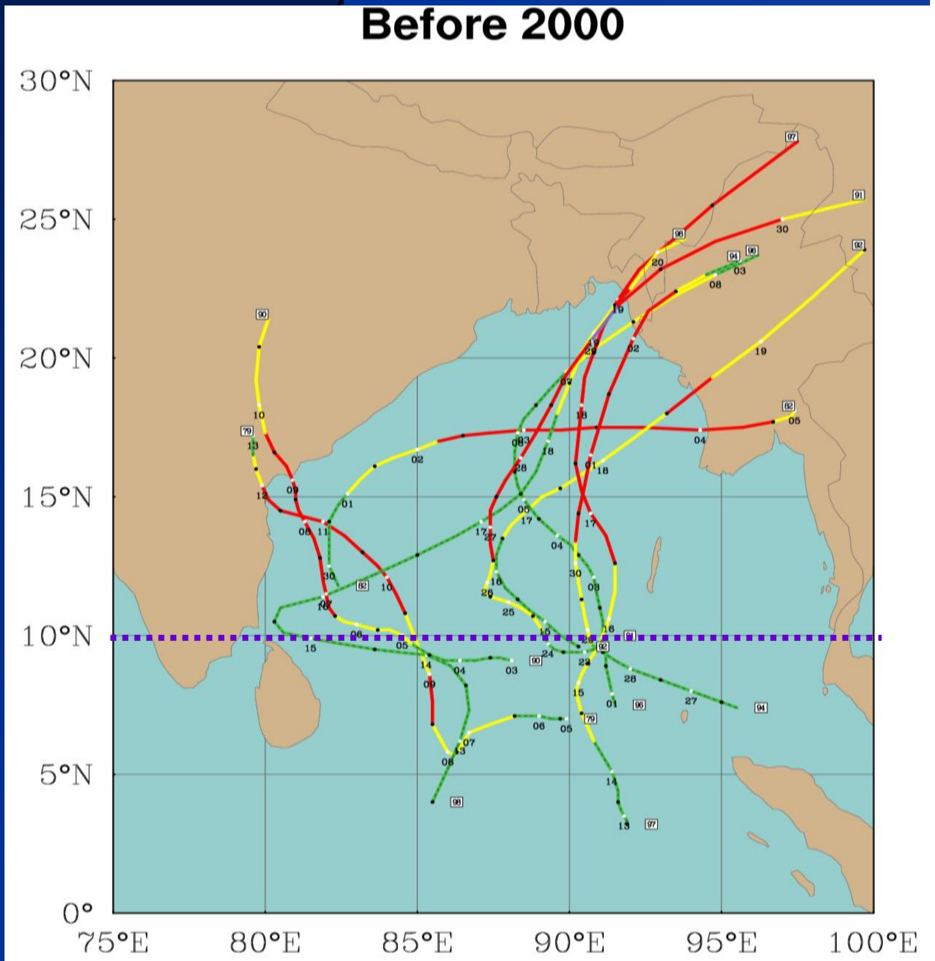
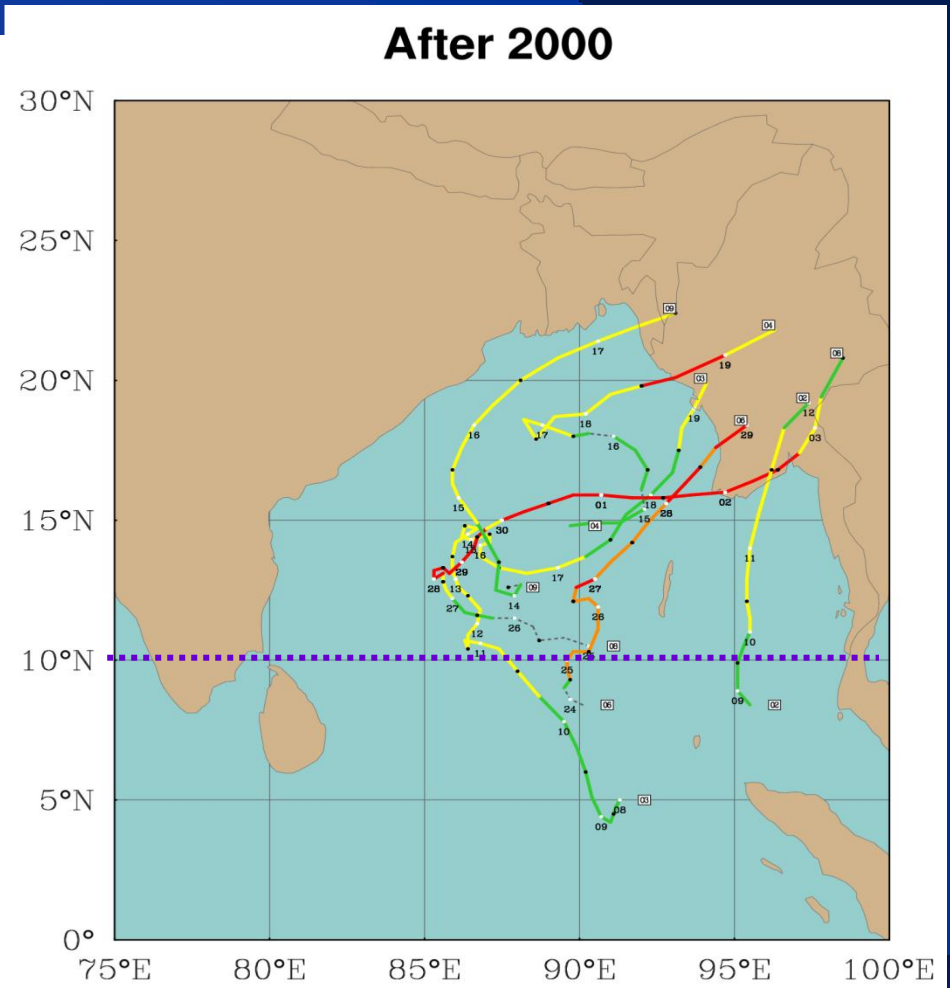
海陆气相互作用
热带低涡　和
孟加拉湾夏季风爆发

Land-Air-Sea Interaction,
Tropical Vortex and
BOB Monsoon Onset

2. Climatology: BOB vortex and seasonal transition





ST TY TS TD TC - - DB

● 0000 UTC Position ○1200 UTC Position/Date [3] Tropical Cyclone year

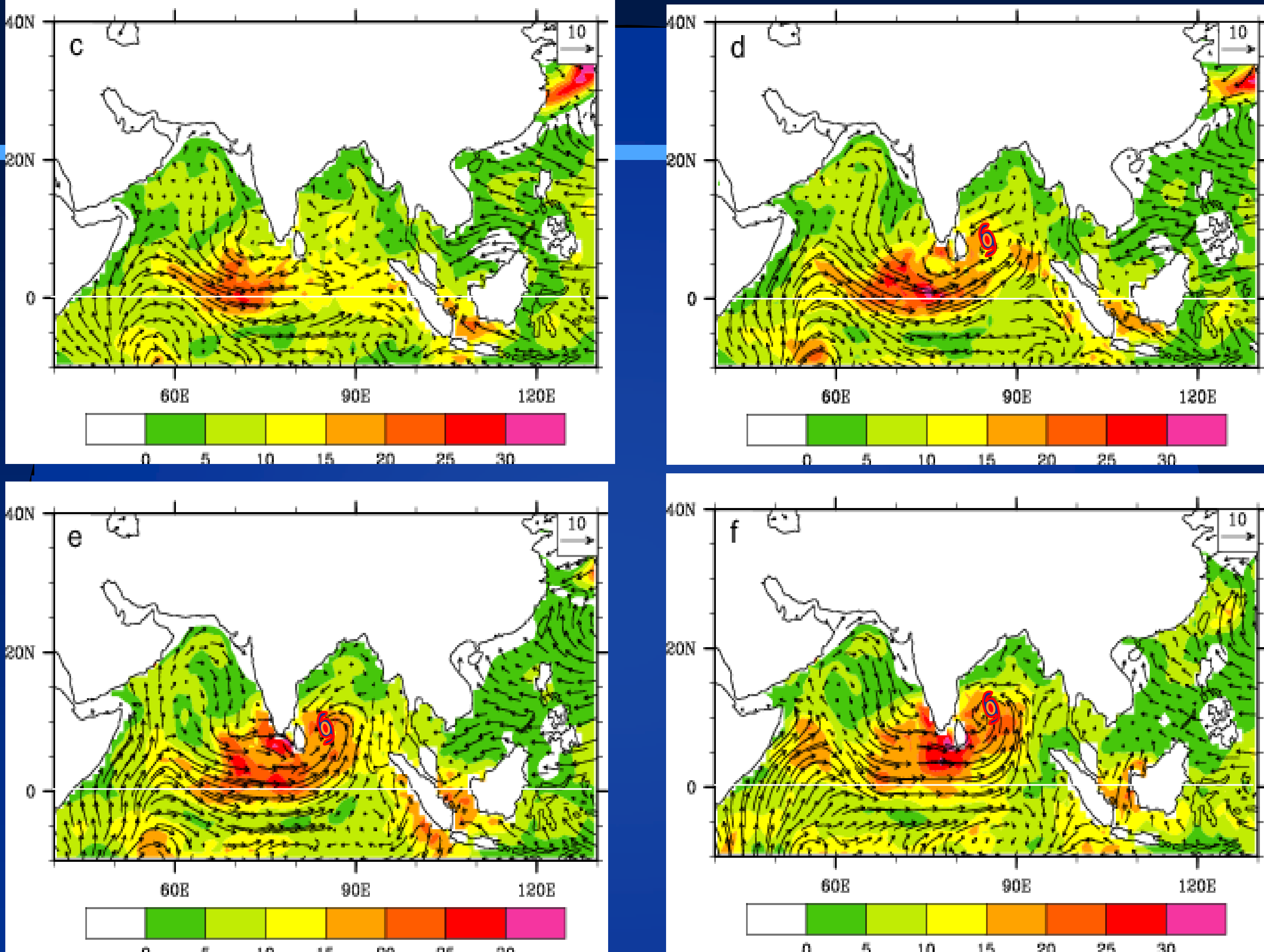


图3 1998年5月6 - 10日平均的表面感热通量（彩色，单位：Wm^{-2}）和10米风场（矢量，单位： ms^{-1}）（a）和海洋混合层上升运动（彩色，单位：$10^{-5}ms^{-1}$）和5米深处海流（矢量，单位： ms^{-1}）（b）的分布；以及5月12日（c）、13日（d）、14日（e）和15日（f）的表面感热加热（彩色，单位：Wm^{-2}）和10米风场（矢量，单位： ms^{-1}）的分布。符号“ ”指示季风爆发涡旋的位置

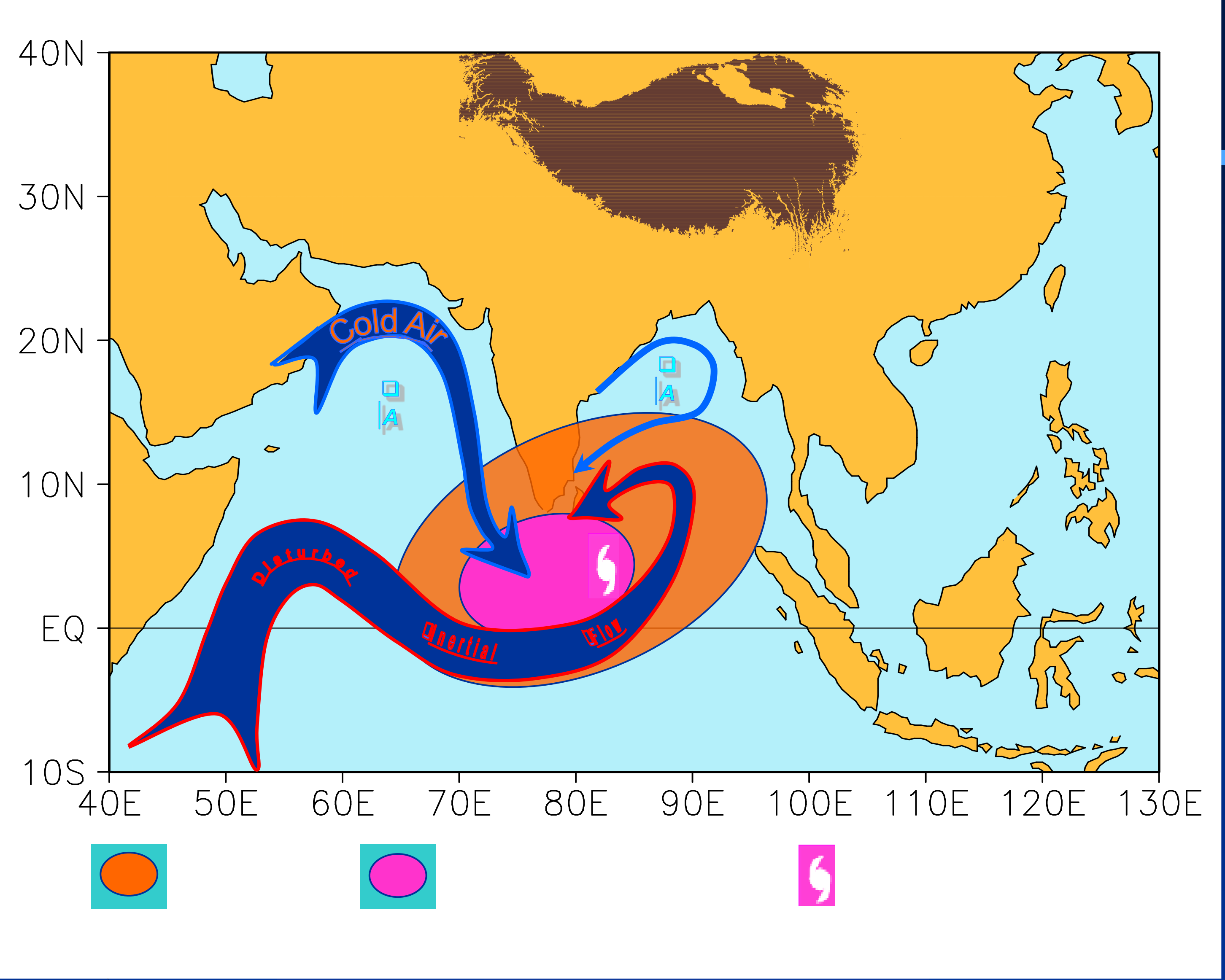
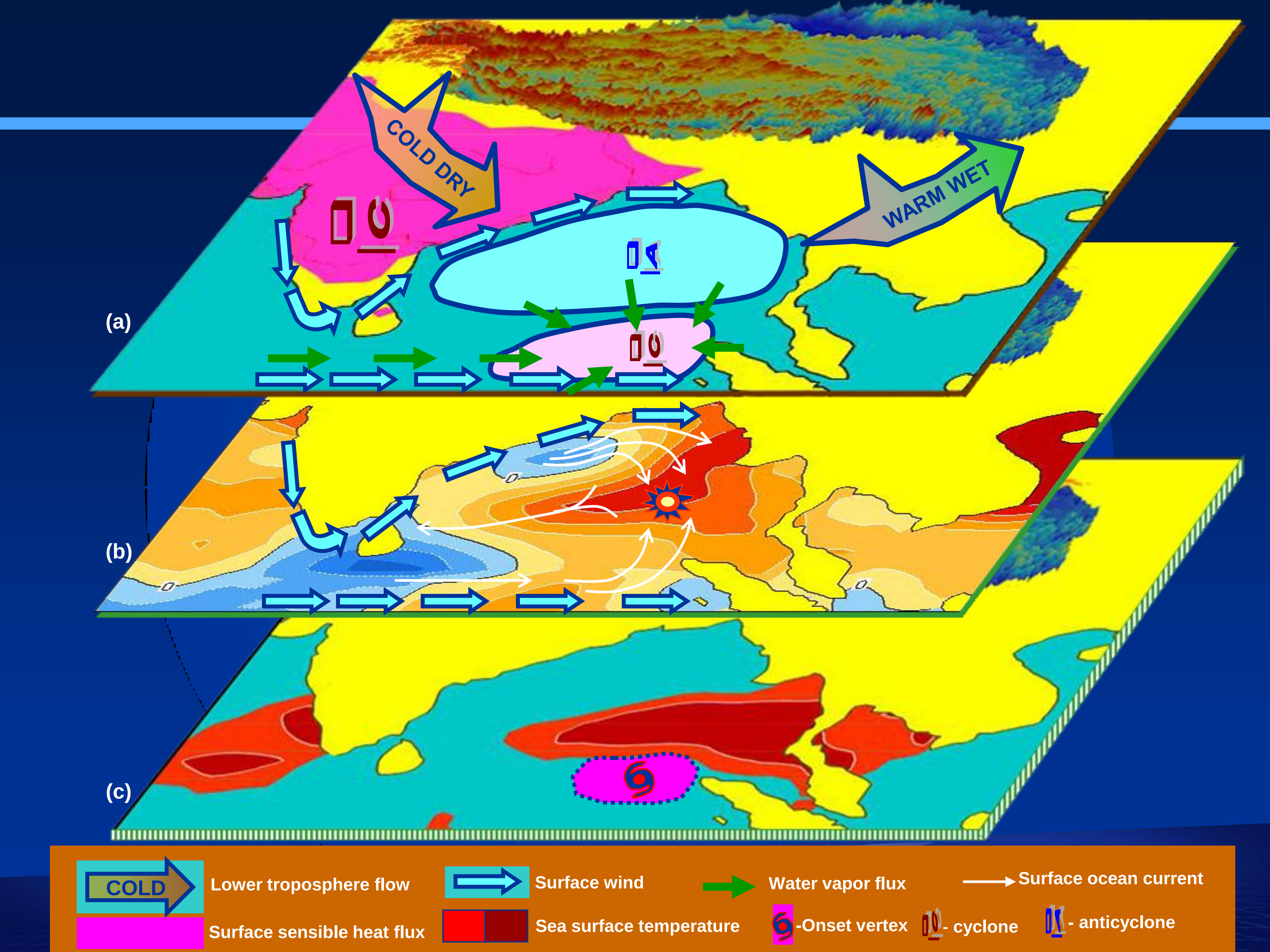
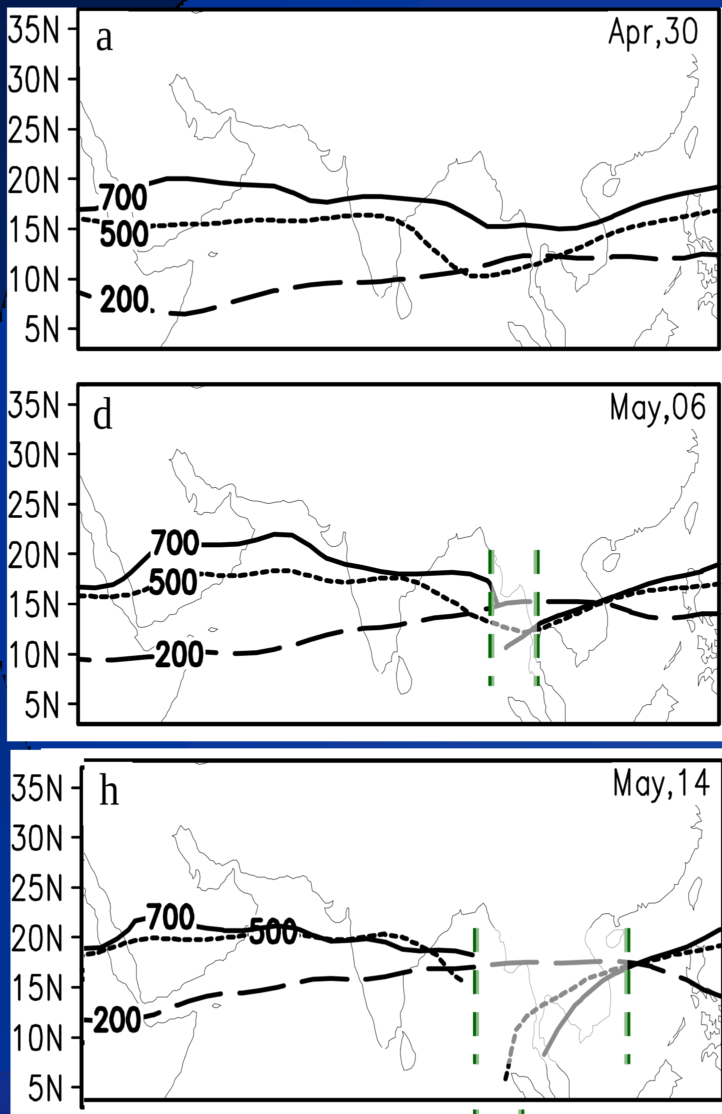


图5 1998年在南亚海气相互作用背景下孟加拉湾季风爆发涡旋形成示意图

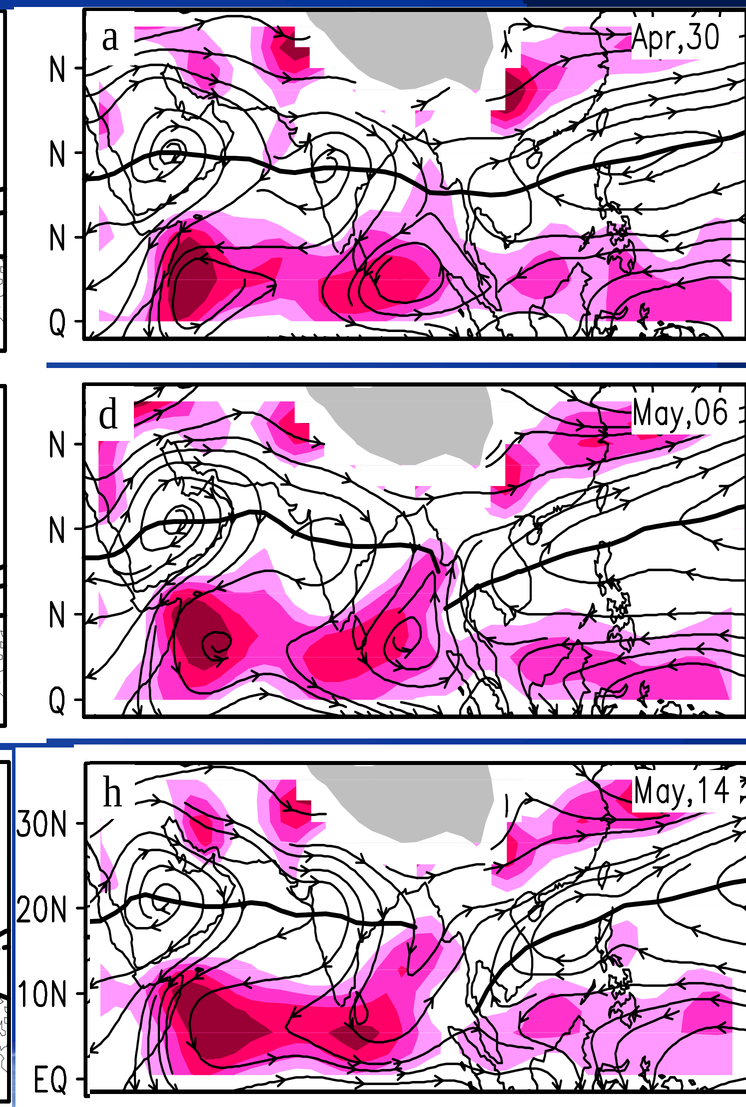
从阿拉伯海反气旋南下的冷空气（蓝色空箭头）与跨赤道的惯性振荡叠加，在位于印度南部的惯性槽的洋面上诱发显著的海表面感热加热，使惯性槽增强并变性（红色空箭头）。槽前空气以气旋性运动向北进入孟加拉湾暖池，与孟加拉湾反气旋南部的偏东气流（蓝色实箭头）在斯里兰卡以东汇合。该处洋面对大气的表面感热加热产生正的能量制造，最终在该地形成了孟加拉湾夏季风爆发涡旋。


COLD DRY
WARM WET
(a)
(b)
(c)
COLD
Lower troposphere flow
Surface wind
Water vapor flux
Surface ocean current
Surface sensible heat flux
Sea surface temperature
-Onset vertex
- cyclone
- anticyclone

2. Climatology: BOB vortex and seasonal transition



Climatological ridgelines



700 mb streamlines + vorticity (10^{-5} s^{-1})

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惯性不稳定和南亚季风爆发

Inertial Instability, ITCZ and SAM Onset

Wu G-X, Liu B-Q.

Guan Y

中国科学院 (CAS)
大气物理研究所 (IAP)
大气科学和地球流体力学数值模拟国家重点实验室 (LASG)

对（2）式求导数，并代入（1）式,令，$v_g=\frac{1}{f}\frac{\partial\phi}{\partial x}\equiv 0$， 则

$$\frac{D^2v}{Dt^2}+\left[f(f-\frac{\partial u_g}{\partial y})-K^2\right]v=f(\frac{\partial u_g}{\partial t}+u\frac{\partial u_g}{\partial x})+Kf(2u-u_g) \qquad (3)$$

令：$\lambda^2=f(f-\frac{\partial u_g}{\partial y})-K^2$

则方程有齐次解： $v=Ve^{i\lambda t}$ (4)

$$\lambda^2=f(f-\frac{\partial u_g}{\partial y})\cdot\begin{cases}>0 & \text{稳定}/stable\\=0 & \text{中性}/neutral\\<0 & \text{不稳定解}/unstable\end{cases} \qquad (5)$$

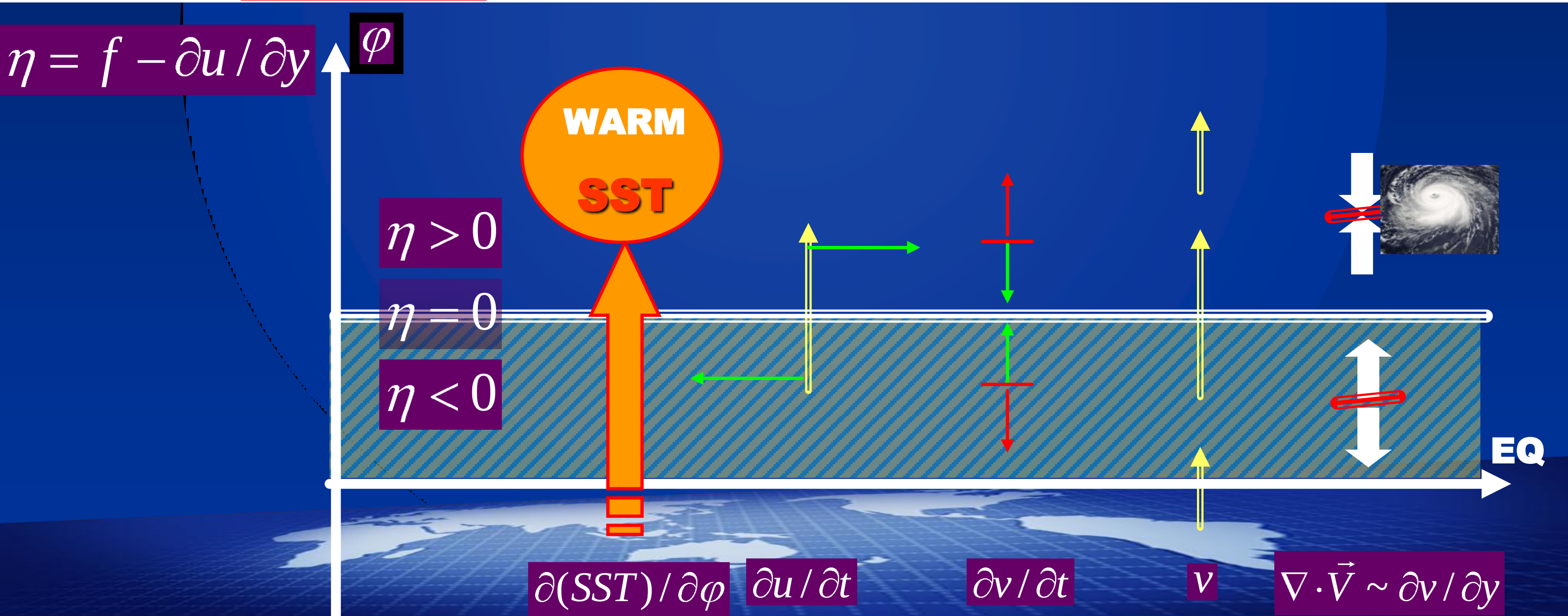
Mechanism of Inertial Instability

Thomas, Holton, Webster,

Q. J. R. Meteorol. Soc. (1999), **125**, pp. 1107–1127

$$-v\left(\beta y-\frac{\partial u}{\partial y}\right)+\alpha u=0, \qquad (20)$$

$$+v\frac{\partial v}{\partial y}+\boxed{\beta y u+\frac{\partial \Phi}{\partial y}}+\alpha v=+v\left(\frac{\partial v}{\partial y}+\alpha\right)+\beta y u_{\mathrm{ag}}=0, \qquad (21)$$



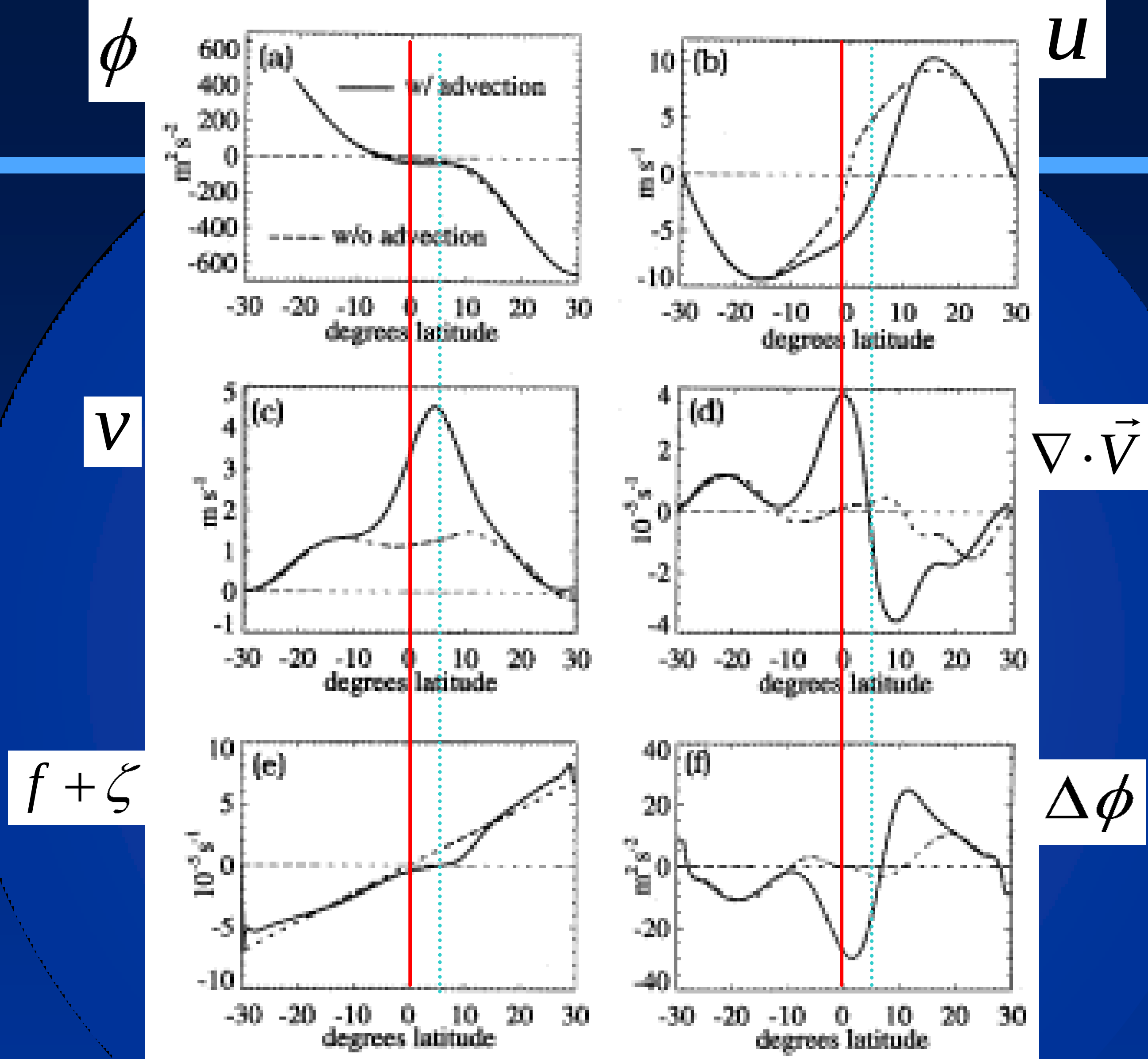


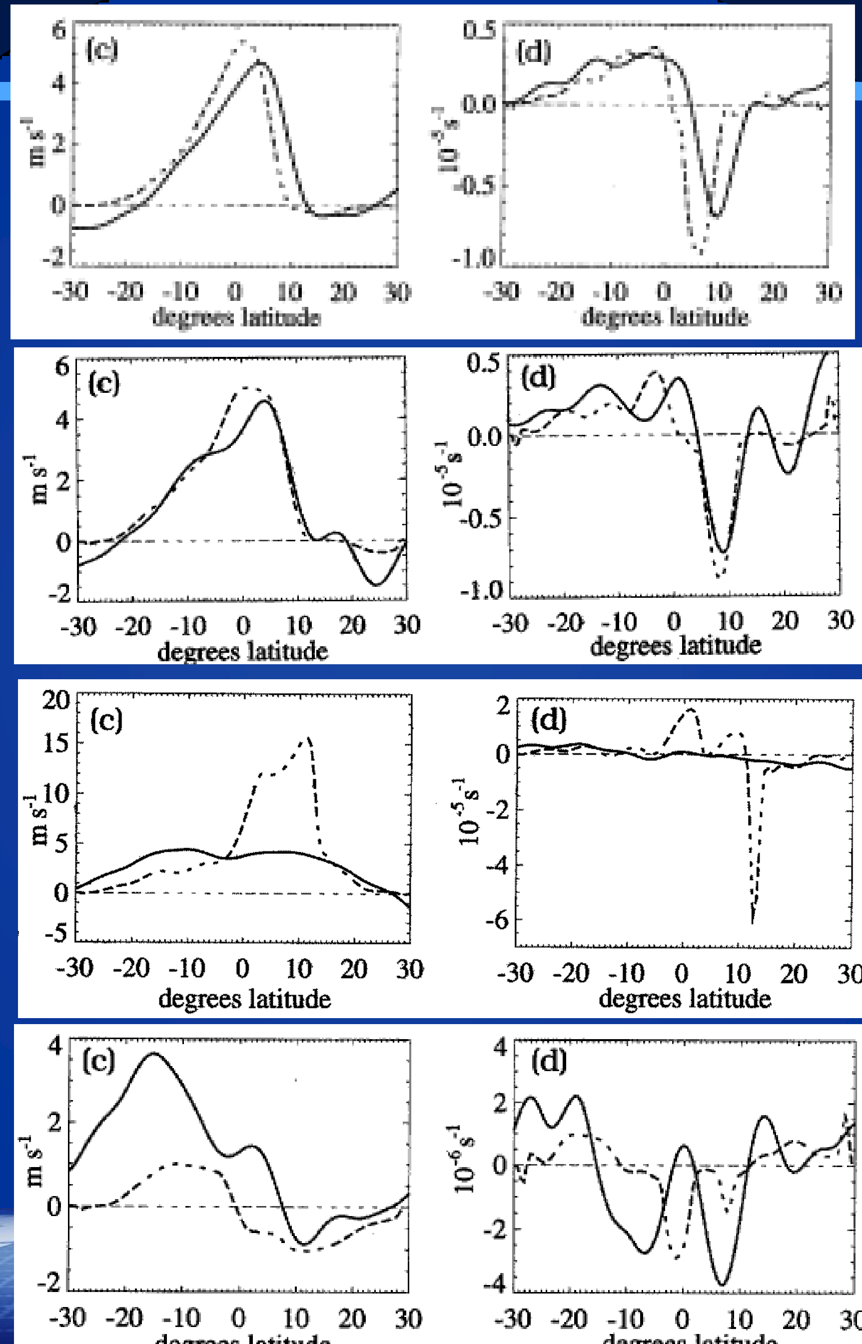
Figure 3. Latitudinal profiles of simulated steady-state parameters obtained using the idealized forcing: (a) geopotential ($m^2 s^{-2}$), (b) zonal wind ($m\ s^{-1}$), (c) meridional wind ($m\ s^{-1}$), (d) divergence ($10^{-6}\ s^{-1}$), (e) absolute vorticity ($10^{-5}\ s^{-1}$) and (f) difference between the simulated and basic state geopotential ($m^2\ s^{-2}$). Solid lines indicate the case with the term $v\partial u/\partial y$ (see text) included; dashed lines indicate the case with the term omitted.

对称不稳定和 ITCZ

Observation (solid line)

Simulation (dotted line)

V | $\nabla \cdot \vec{V}$



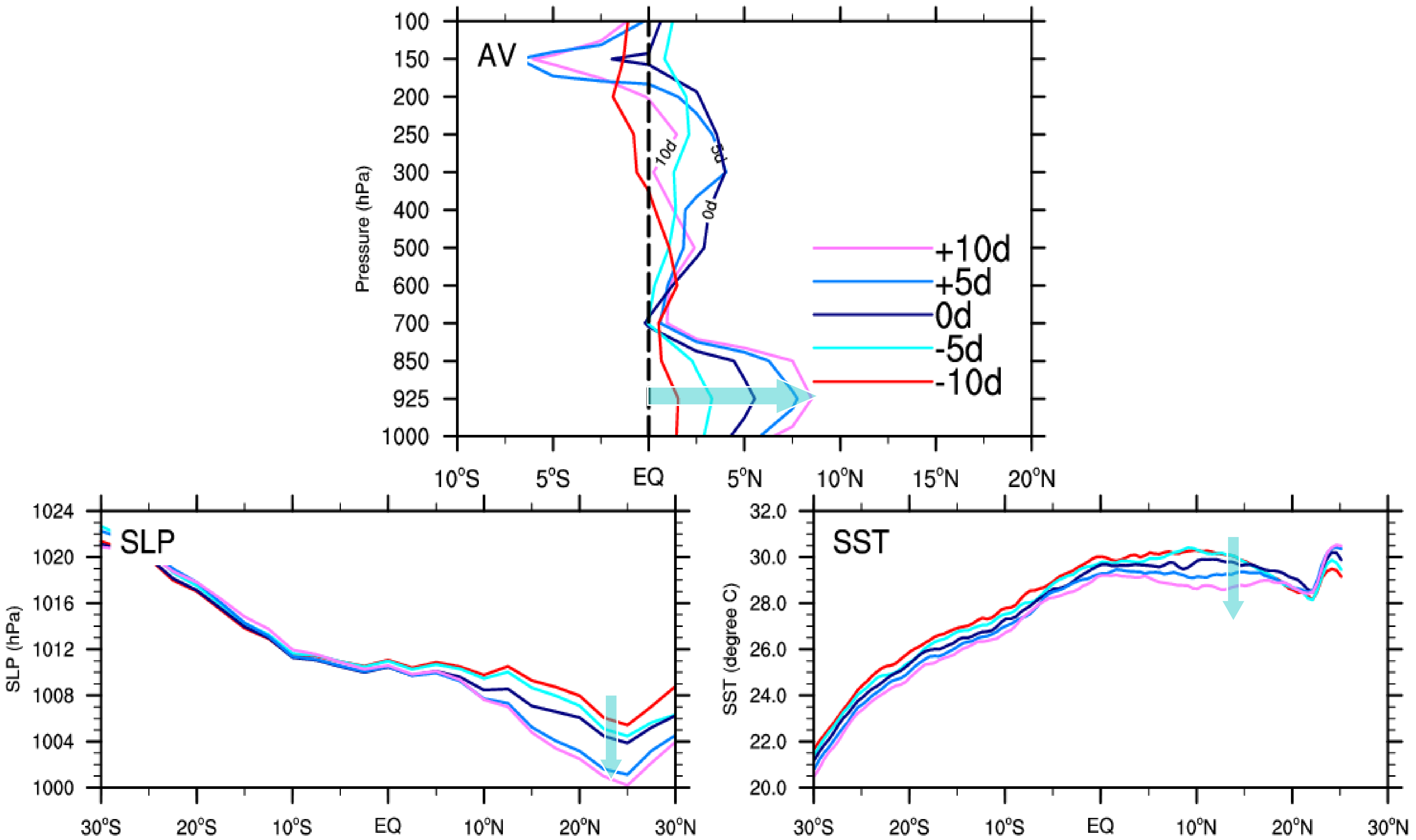
120°W and 90°W: **E-Pacific**

30°W and 10°W **E-Atlantic**

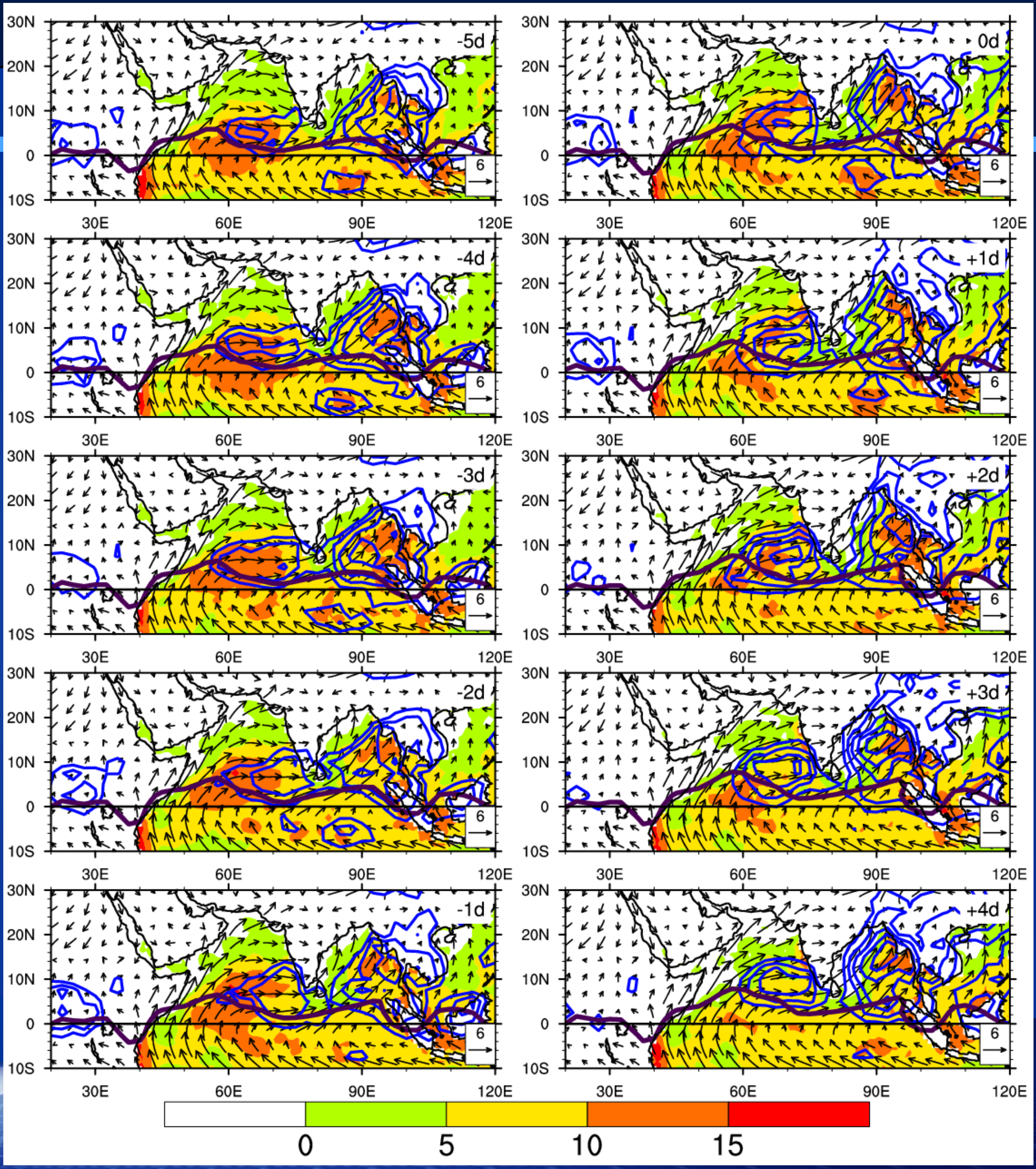
60°E and 80°E. **Arabian Sea**

165°E and 165°W **Central Pacific**

The height-latitude cross section of the ZERO absolute vorticity contour (top) and the SLP (bottom) along 60^{o}E from -10d to +10d every 5 days in terms of the ISM onset date (NCEP)



The evolution of the surface sensible heating (shading, W m^{-2}), the zero AV contour (modena contour, s^{-1}), the **OLR (blue contours**, W m^{-2}, contour intervals 10 starting from 180) and the 10m wind field (vectors, m s^{-1}) from -5d to +4d in terms of the ISM onset date (NCEP)



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Monsoon Rainfall

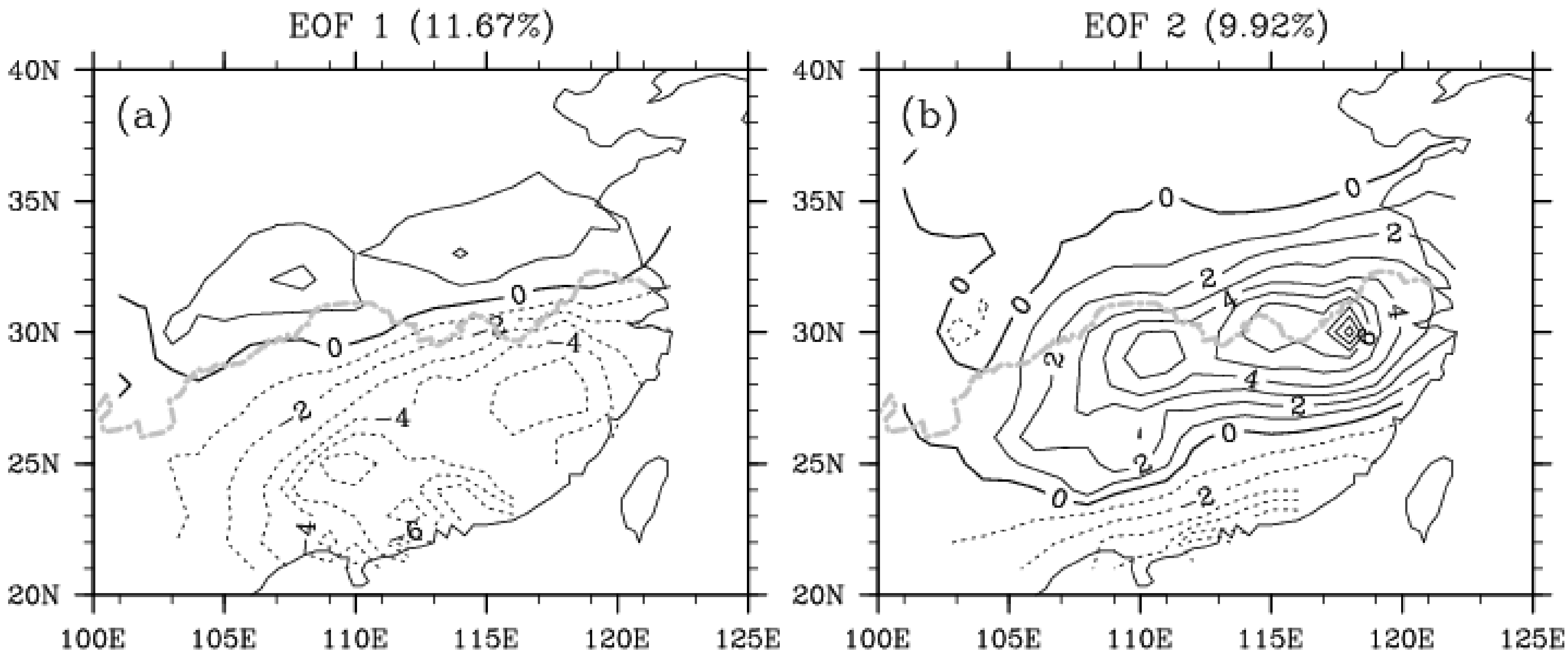
Subtropical Anticyclone

ISO in the Tropics

20-50-day Oscillation of the Summer Yangtze Rainfall in Response to Intraseasonal Variations in the Subtropical High over the Western North Pacific and South China Sea

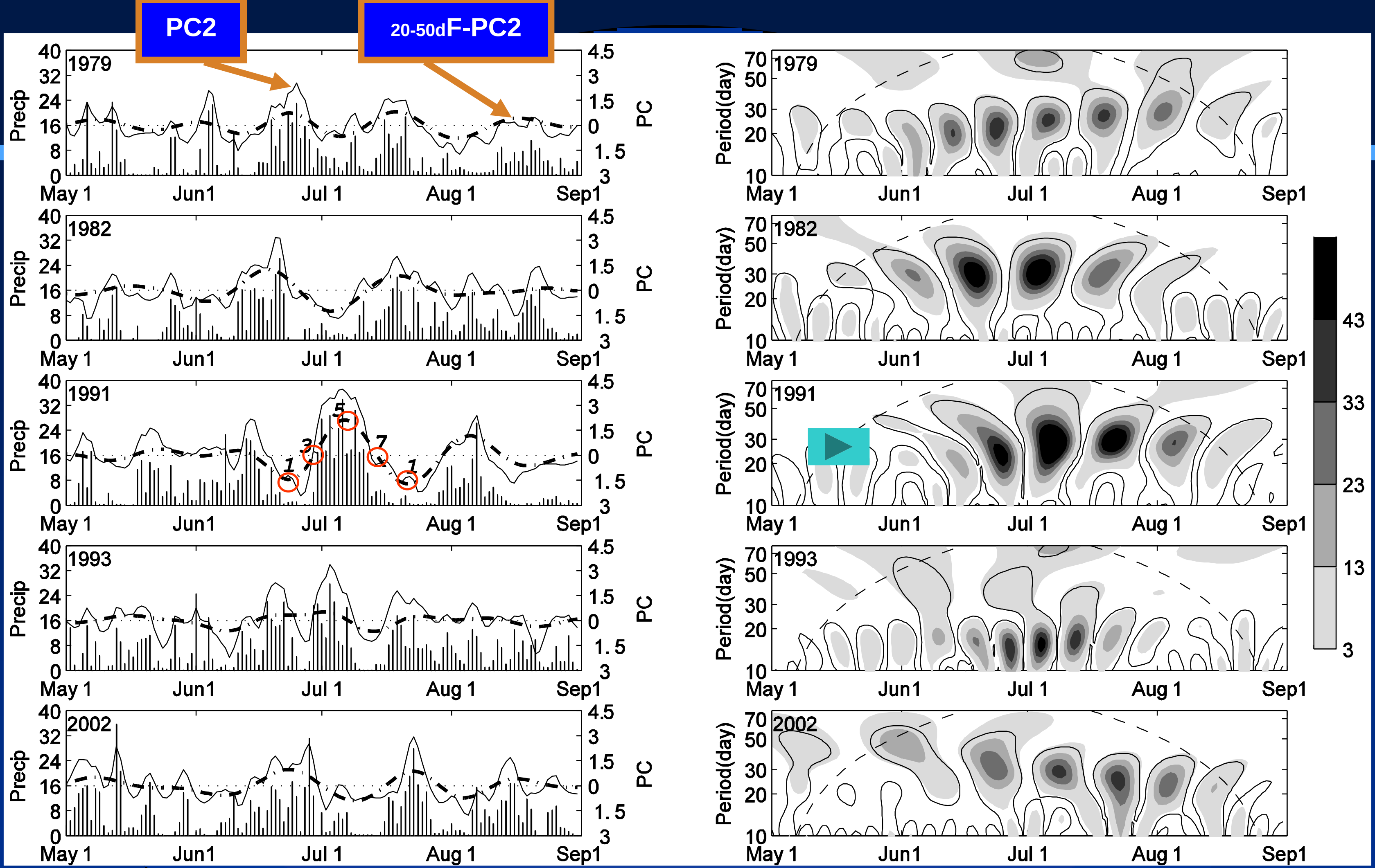
Mao Jiangyu, Zhang Sun, and Wu Guoxiong

LASG, Institute of Atmospheric Physics *Climate Dynamics* 2009



5-day running-mean daily rainfall over eastern China

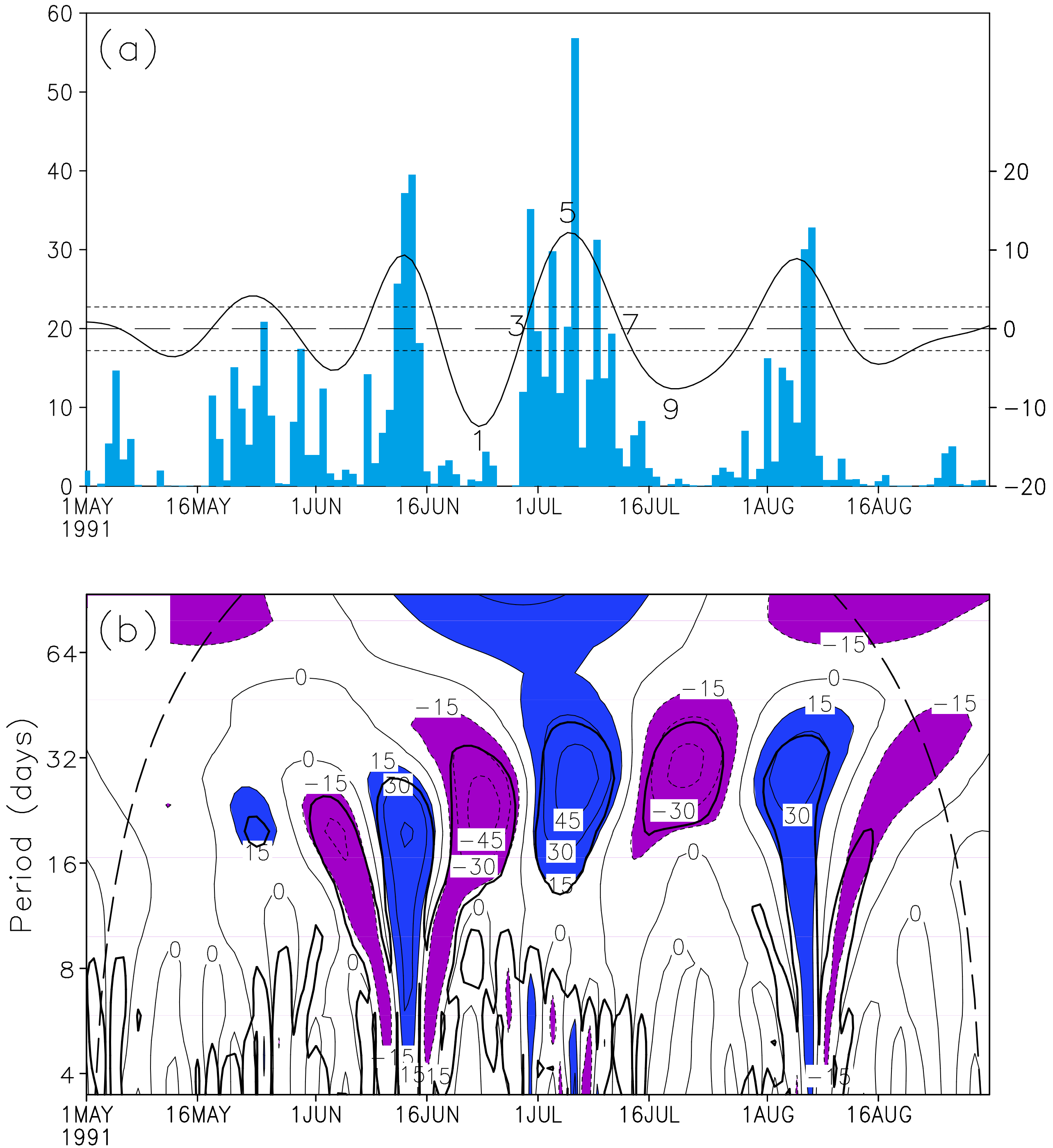
The loadings have been scaled by one standard deviation of the corresponding PC with unit of mm day-1. Solid and dashed contours indicate positive and negative loadings respectively.



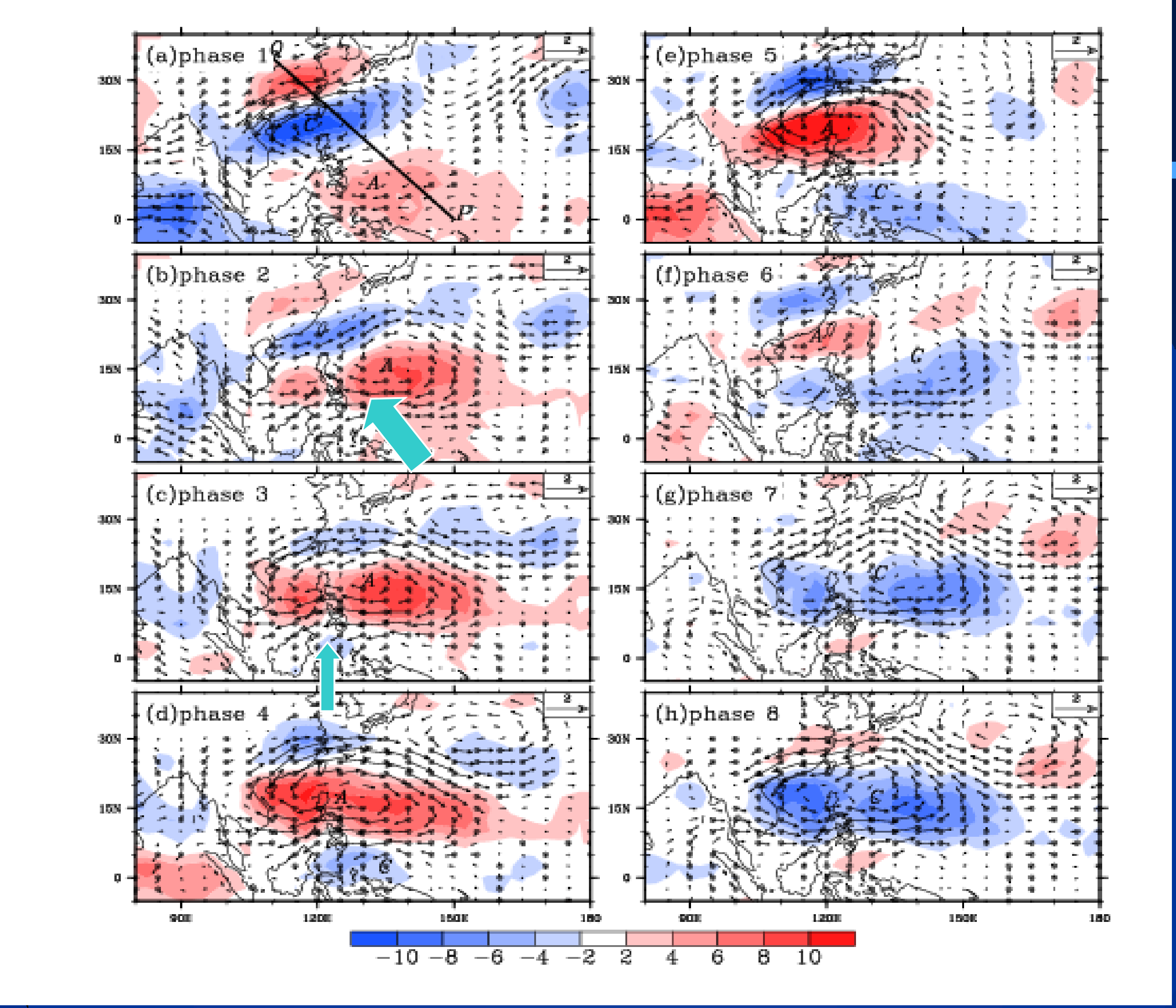
(Left panel) The area-averaged daily rainfall (mm day-1, with scale on the left-hand ordinate) over the Yangtze Basin (32.5°-36°N,110°-125°E) , Numbers 1, 3, 5, and 7 represent the phases of the 20-50-day oscillation

(Right panel) Wavelet power spectrum (shading) of PC2 in left panel. Solid contour > 95% confidence level for a red-noise process with a lag-1 coefficient of 0.90.

Dominant Periods Above 20-day or below 20-day in most summers

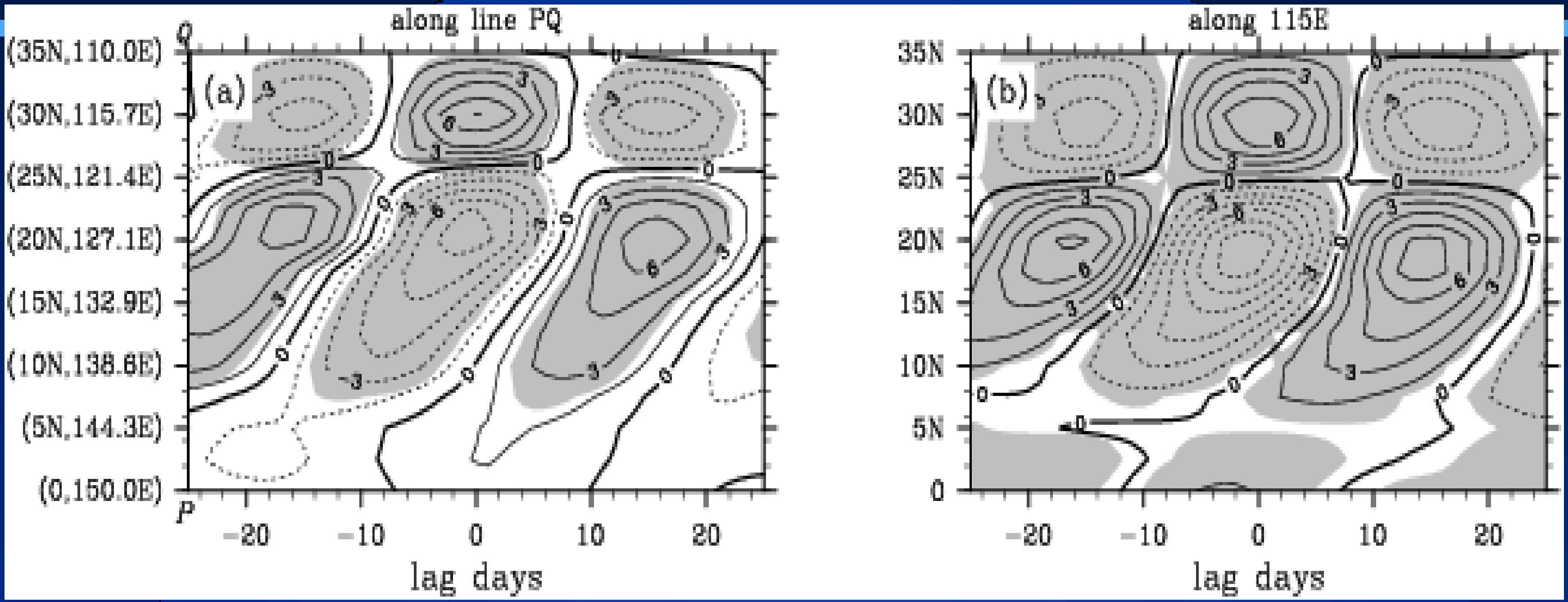


(a)
1MAY 1991
16MAY
1JUN
16JUN
1JUL
16JUL
1AUG
16AUG
(b)
Period (days)

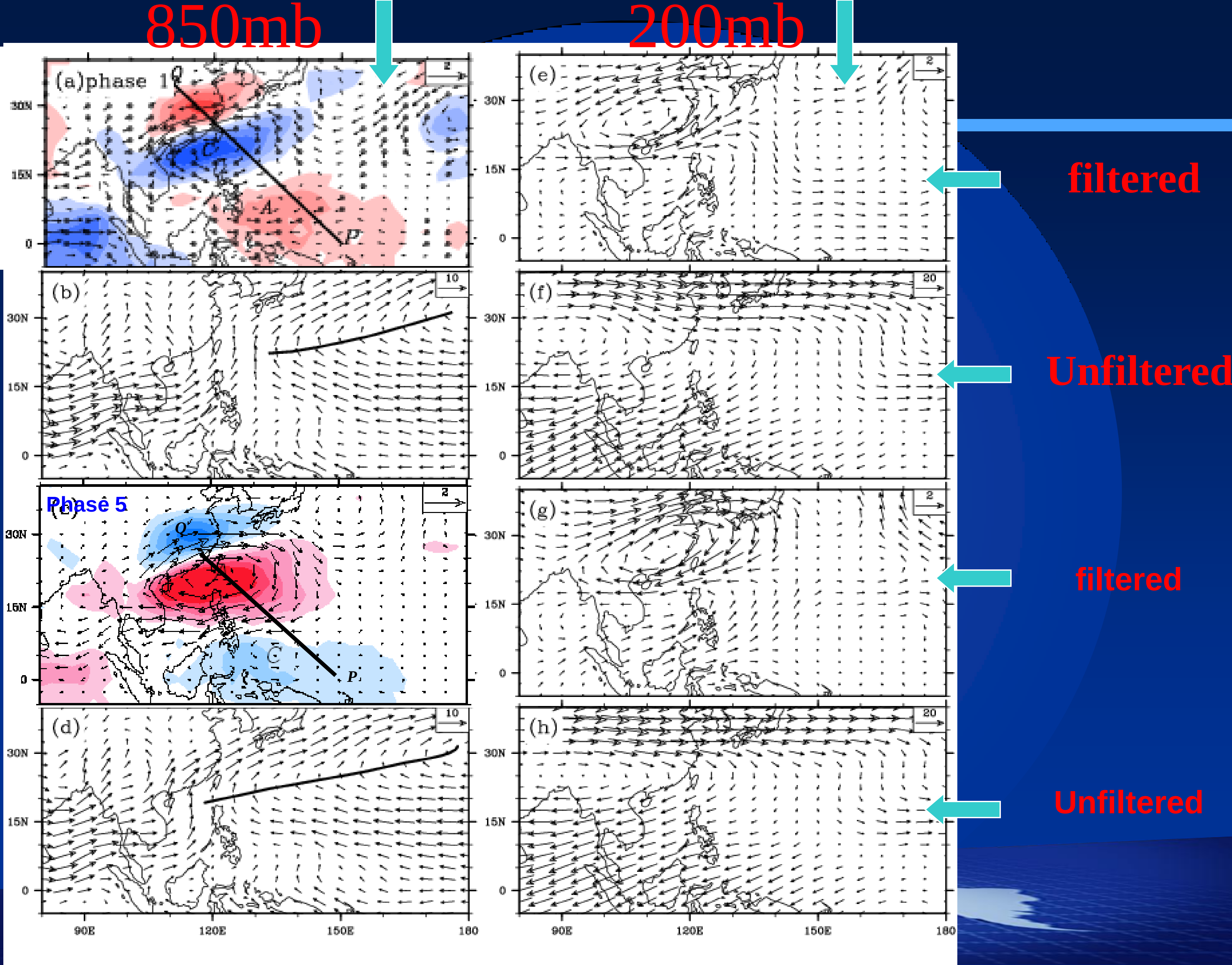


Rossby wave-like coupled circulation–convection system

Composite evolutions of the 20-50-day filtered OLR (shading, W m-2) and 850-hPa winds (vectors, m s-1). Open circles indicate grid points where the filtered wind anomalies are significantly different from zero at the 95% level (based on the *t* test) in at least one of the wind components (zonal or meridional). Thick solid line from point P (0°, 150°E) to point Q (35°N, 110°E) in (a) indicates the cross section PQ along which lagged regression is plotted.



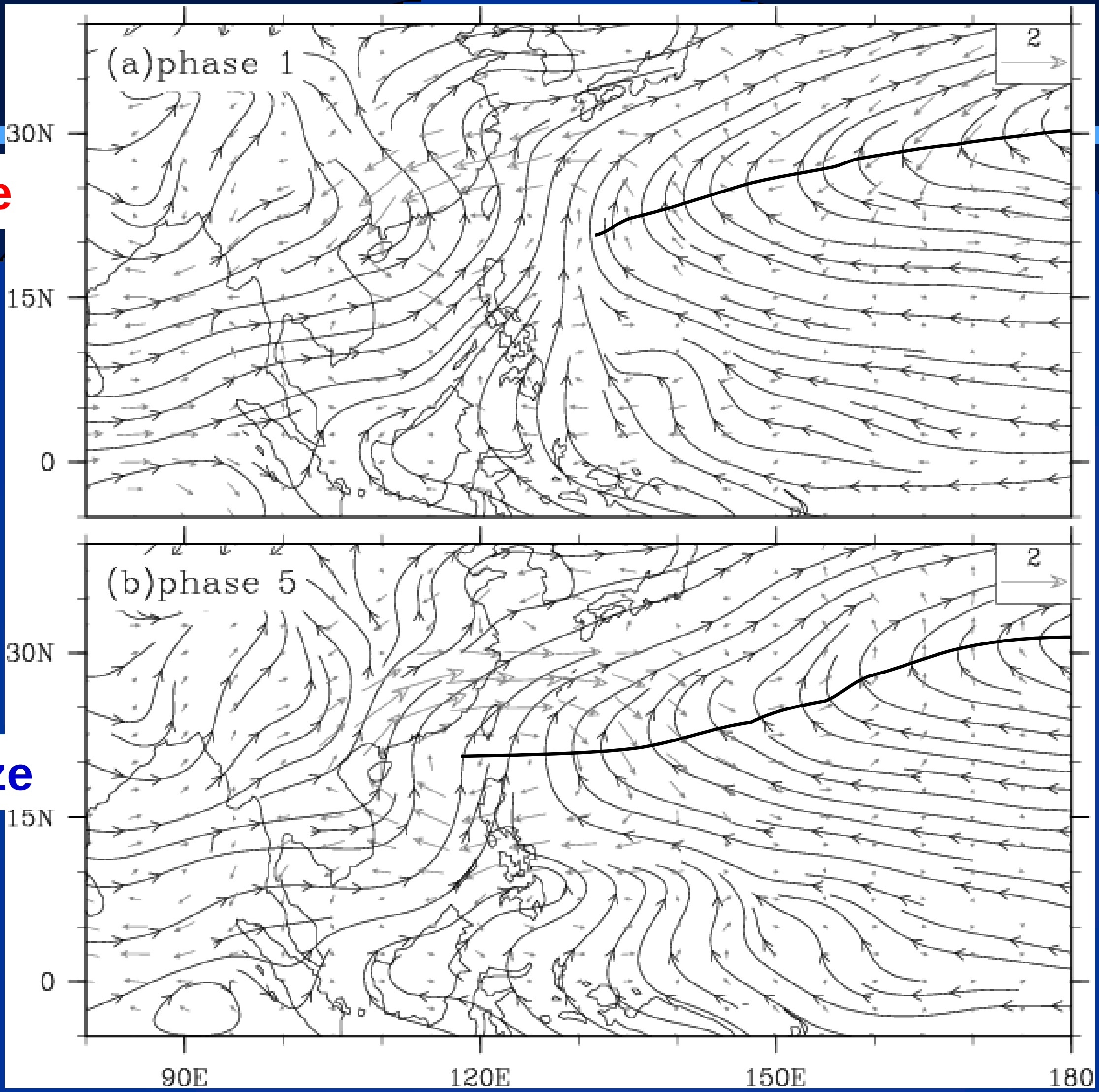
Lagged regression of OLR anomalies (W m-2) onto the 20-50 day ISO index of the Yangtze rainfall for day -25 to day 25 with a lag of 1 day along (a) line PQ (as indicated in Fig. 6a) and (b) 115°E. OLR anomalies significantly different from zero at the 95% confidence level are shaded.



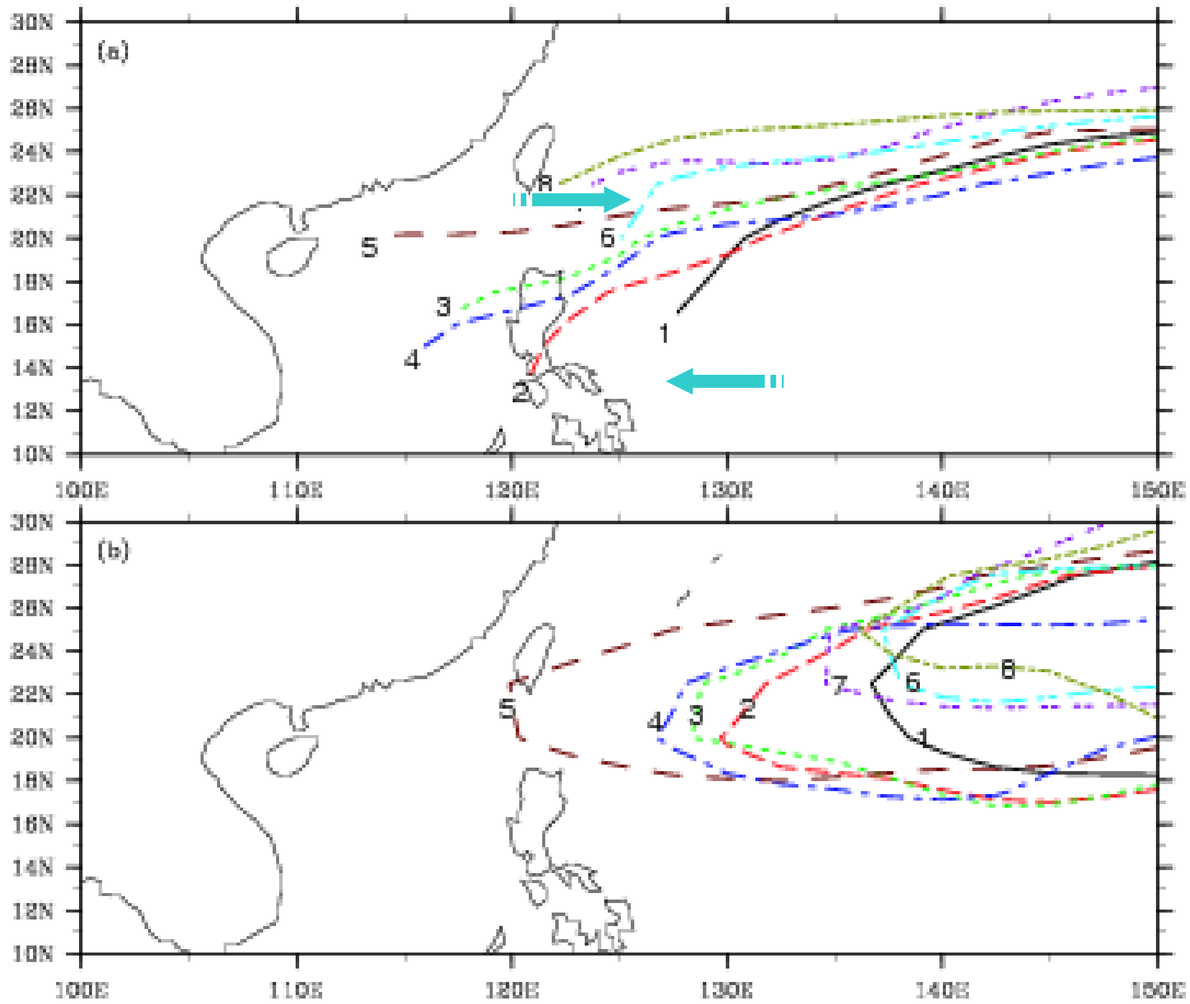
850mb
200mb
(a)phase 1
(b)
Phase 5
(d)
(e)
(f)
(g)
(h)
filtered
Unfiltered
filtered
Unfiltered
30N
15N
0
90E
120E
150E
180

Driest Yangtze

Wettest Yangtze



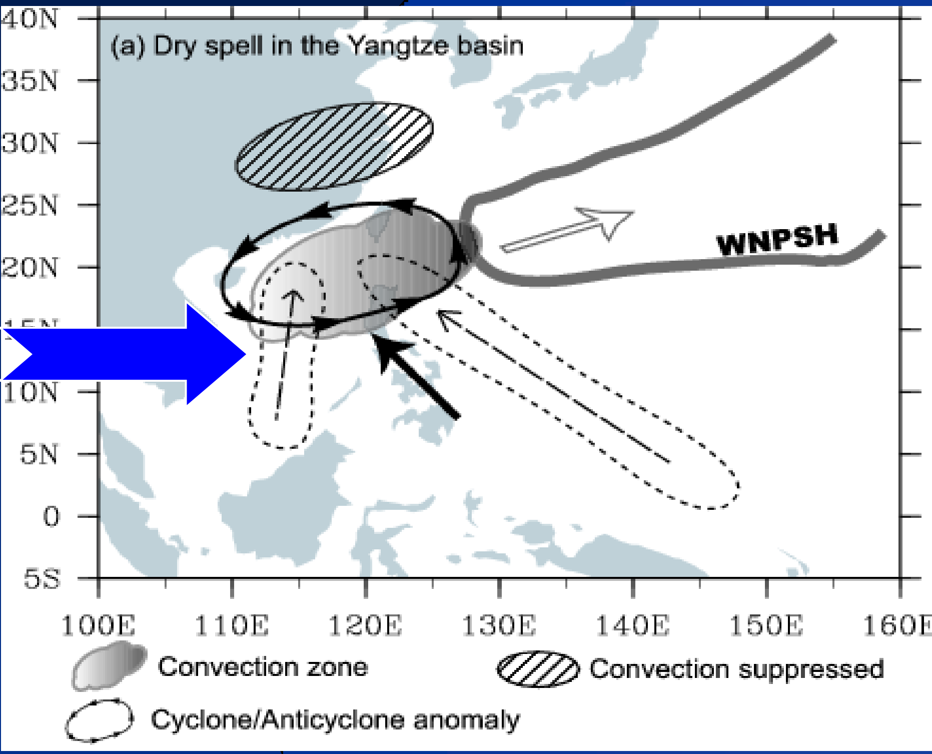
Composite unfiltered (streamline) and filtered (arrow) 850-hPa winds (m s-1) for the (a) driest and (b) wettest ISO phases of the Yangtze rainfall. Solid line denotes the ridgeline of the western North Pacific subtropical high.

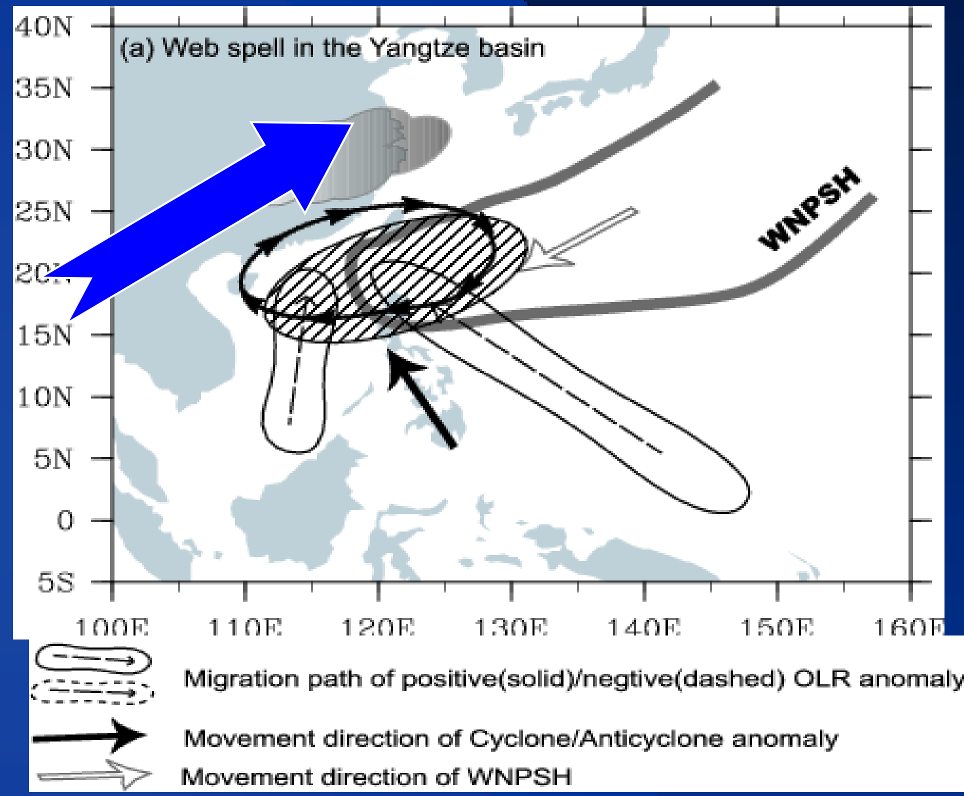


700-hPa ridgelines

5880- contour

Abrupt 3/8-period shift of westernmost point of ridgeline (a) Composite 700-hPa ridgelines of the western North Pacific Subtropical High for phases 1 to 8. (b) Composite 500-hPa geopotential heights (indicated by 5880-m contour) for phases 1 to 8. Numbers 1 to 8 represent the phases of the 20-50-day ISO, respectively.





Schematic diagram showing that the intraseasonal oscillation of Yangtze summer rainfall arises in response to intraseasonal variations in the western North Pacific subtropical high (WNPSH), which in turn is modulated by a northward and northwestward propagating Rossby wave-like system.

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Intraseasonal modulation of tropical cyclogenesis in the western North Pacific: A case study

毛江玉　吴国雄

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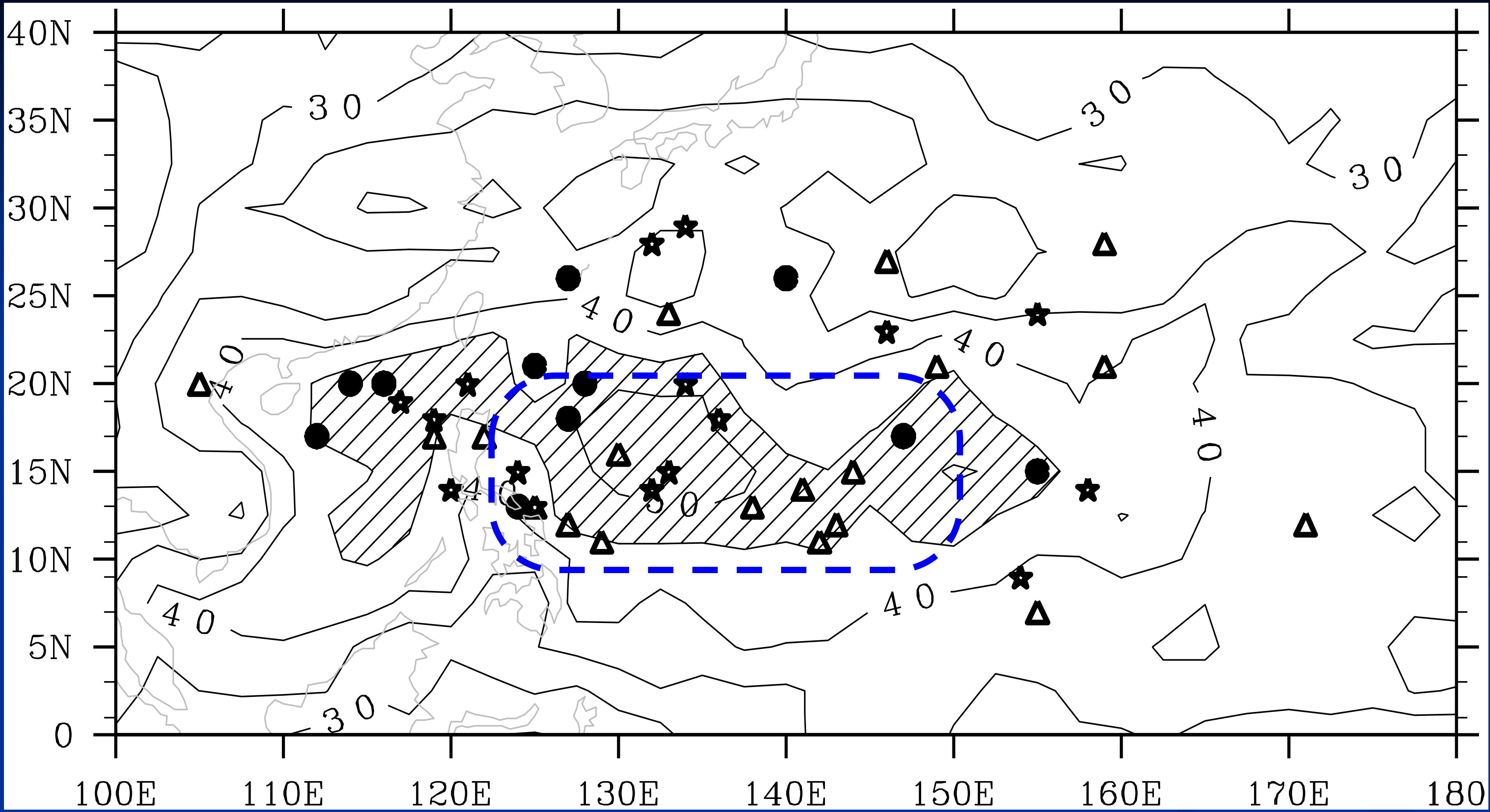
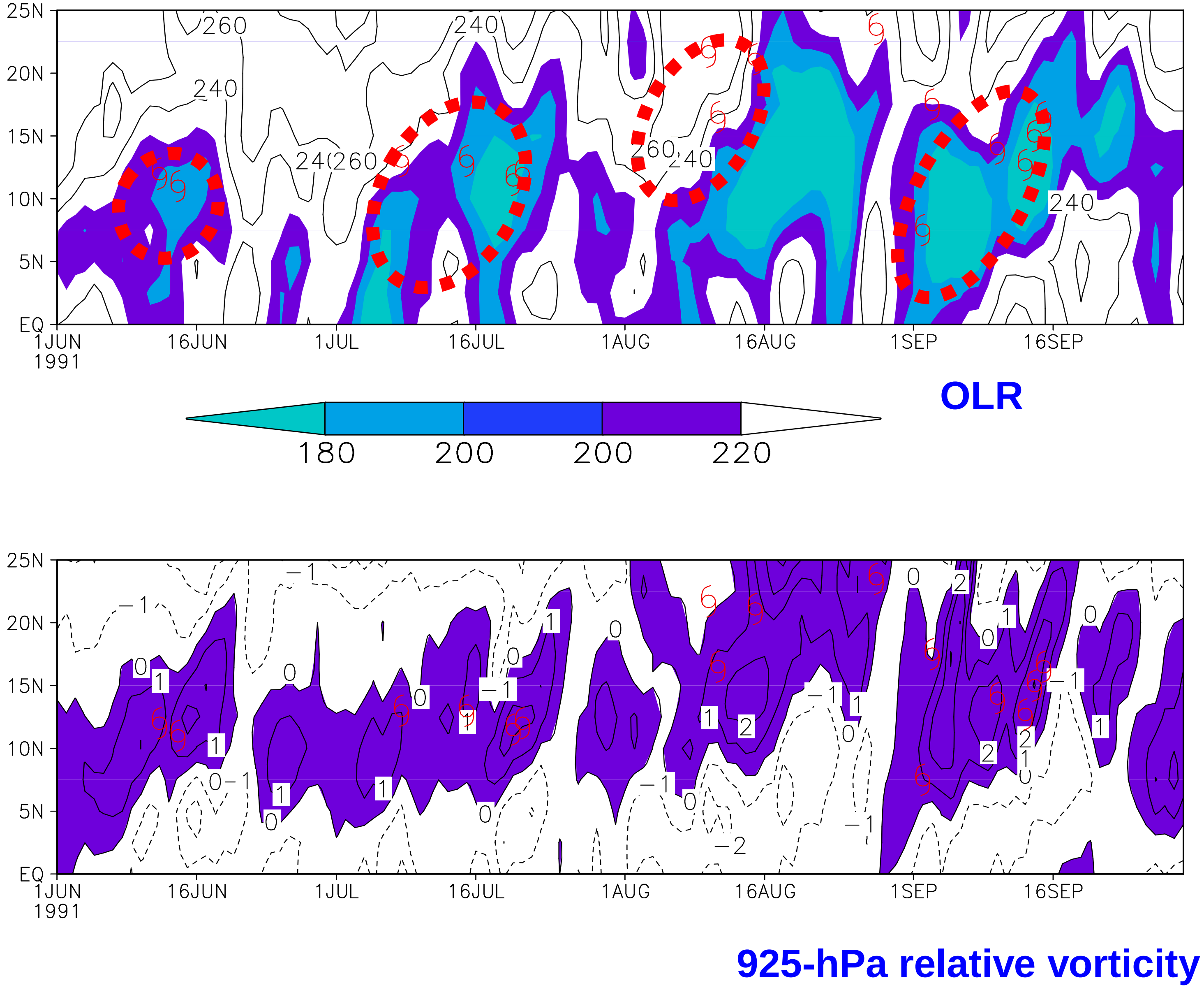
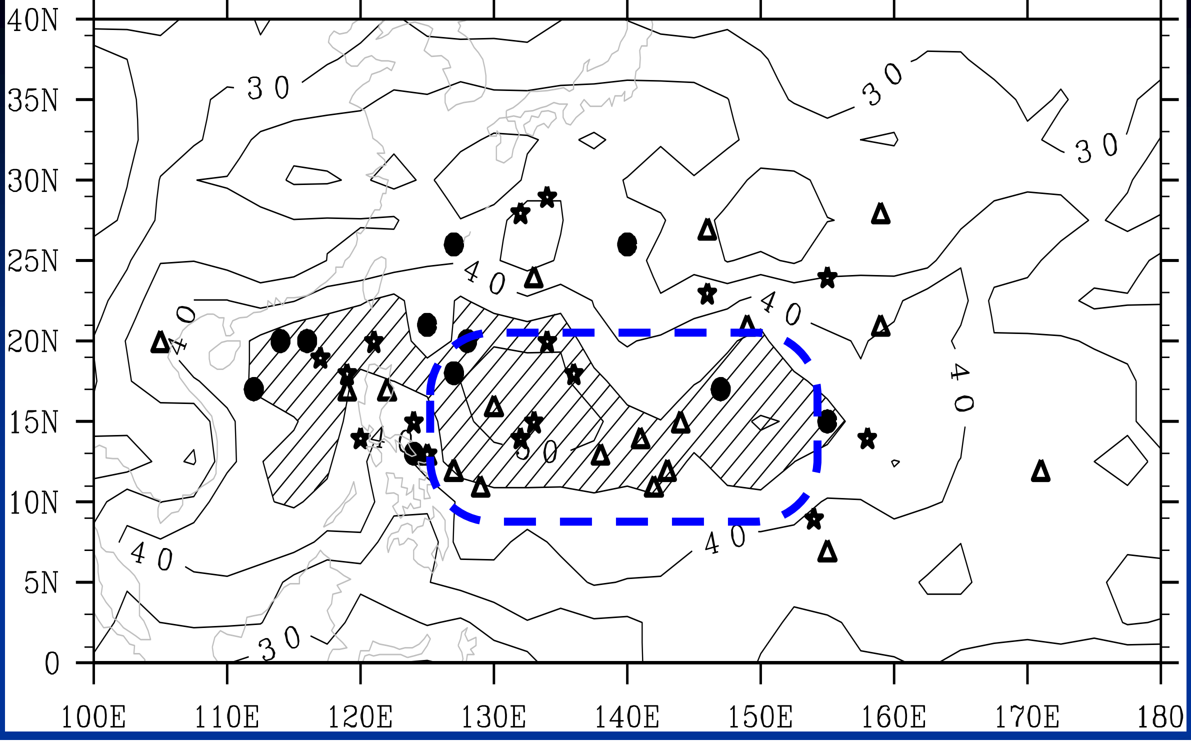
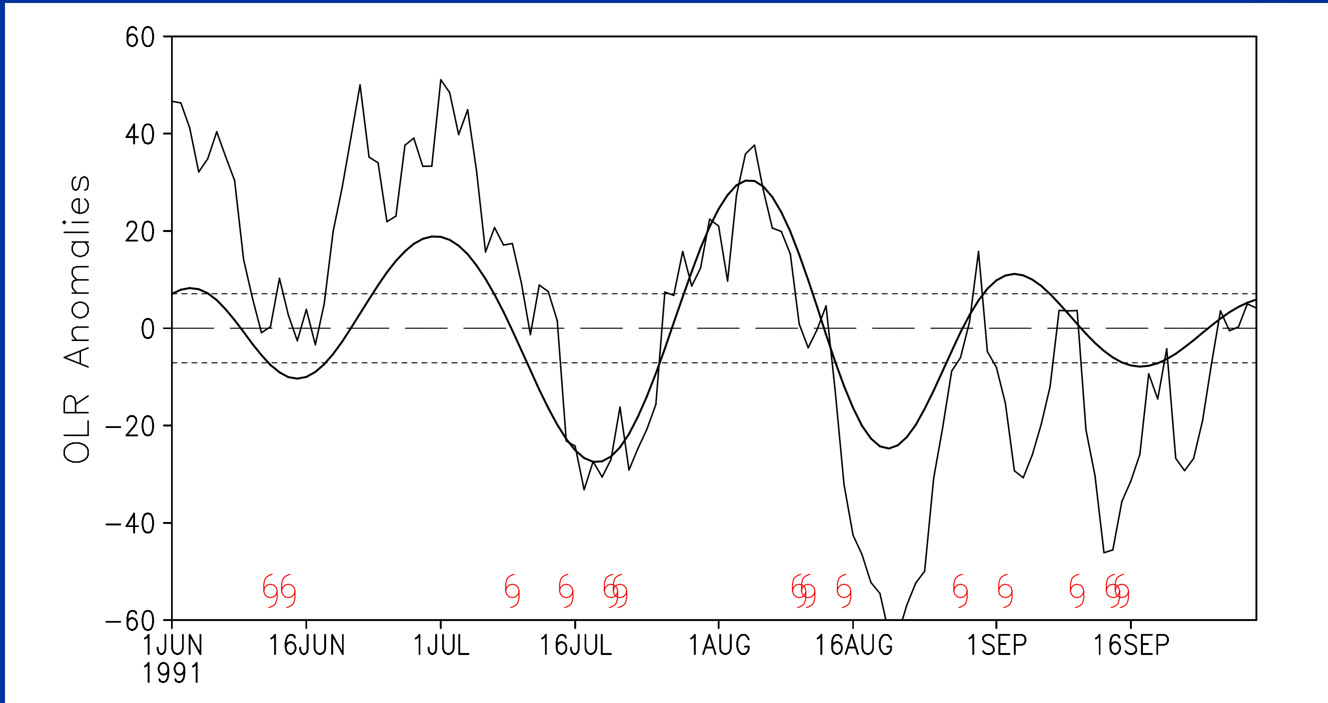


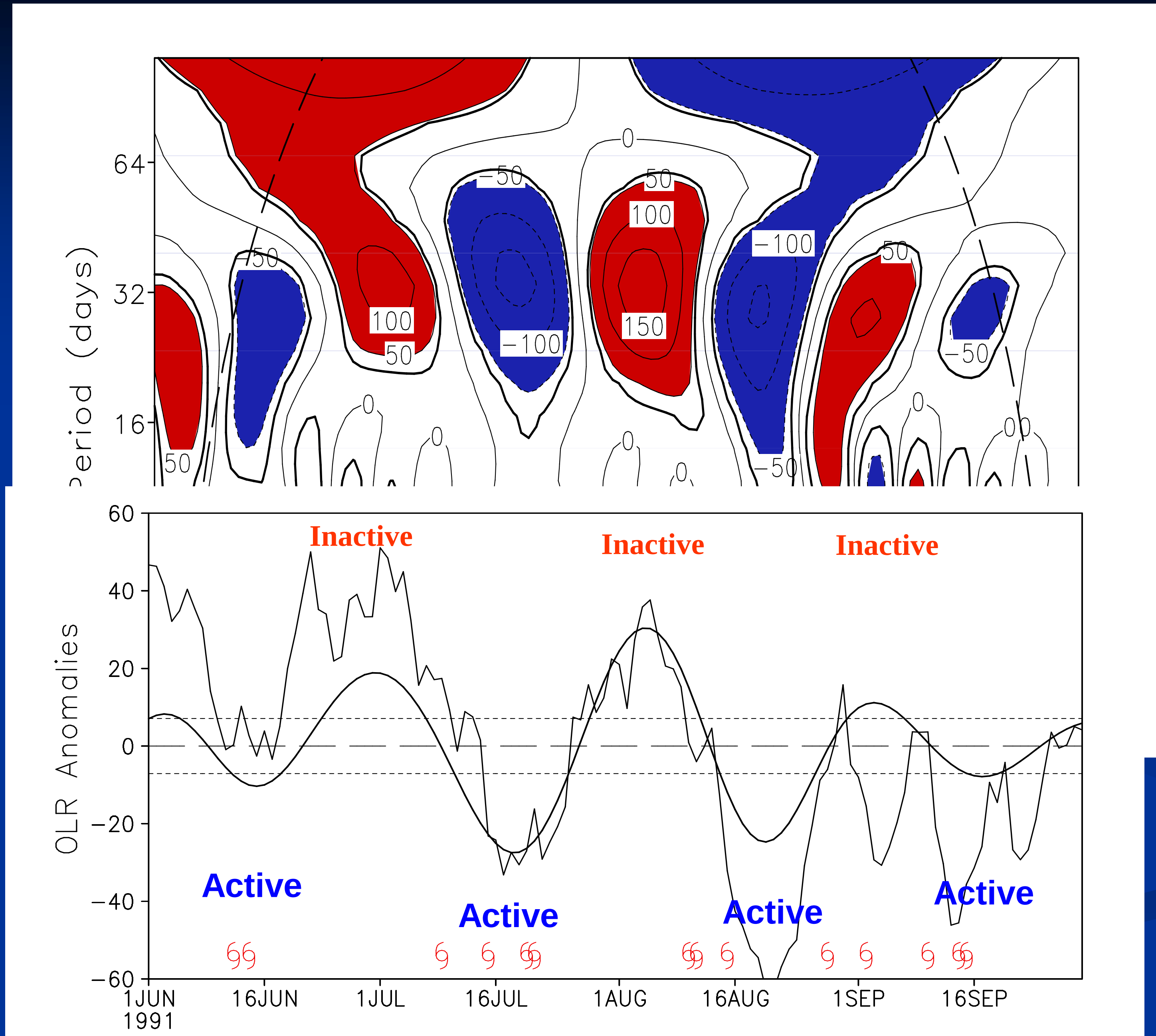
<u>Subseasonal Standard deviations of OLR anomalies</u> (Contours, W m^{-2}) and initial genesis positions of tropical cyclones for the 1991 summer (Jun~ Sep). Hatches denote standard deviations greater than 45 W m^{-2}. **Triangle symbols, stars and filled circles represent tropical depression, tropical storm and typhoon** respectively



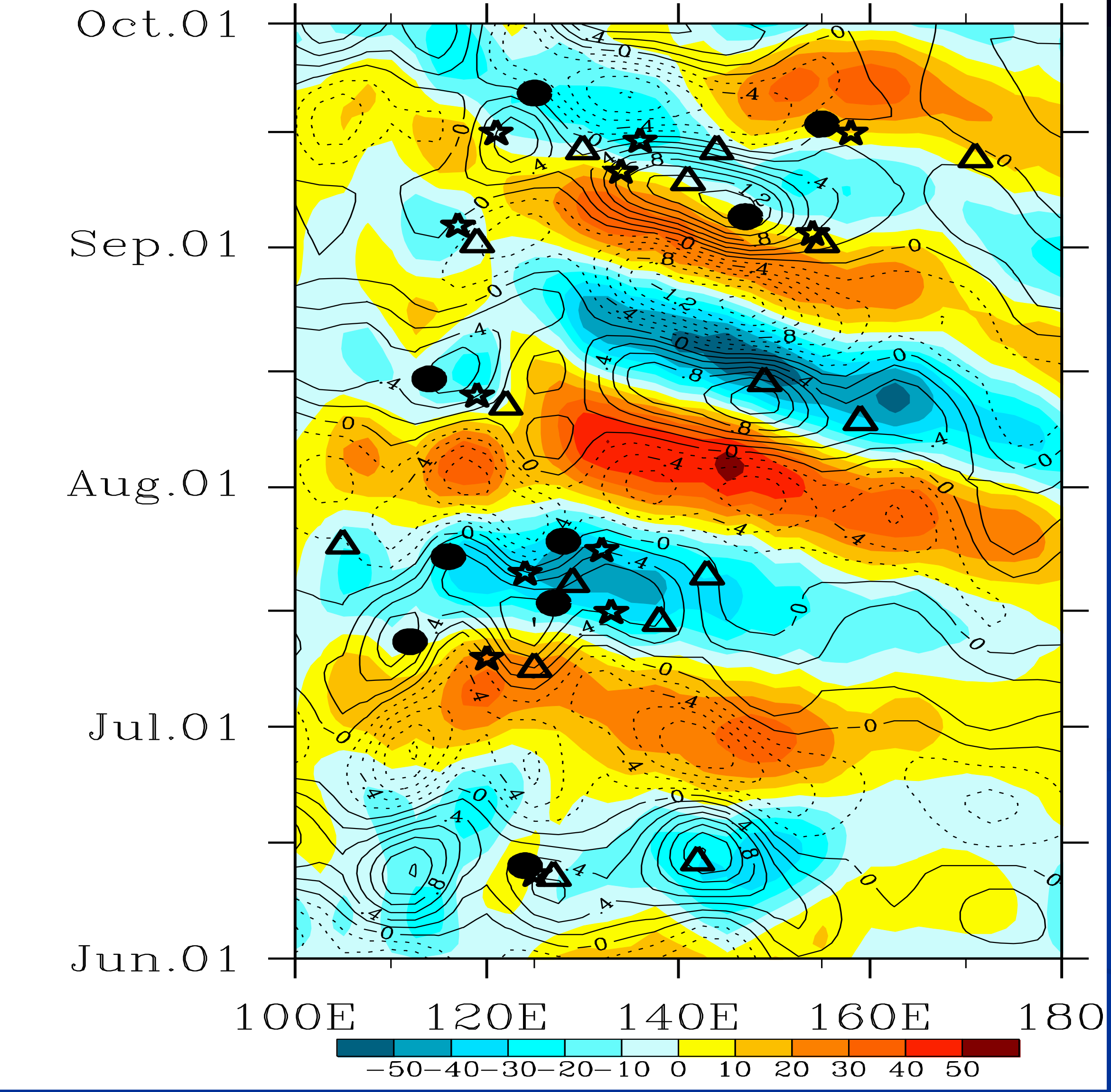
Time-latitude cross section (125-155E) of daily OLR (W m^{-2}) and 925-hPa relative vorticity (s^{-1}) superimposed on initial position of tropical cyclogenesis from 1 June to 30 September 1991 (Four episodes)


40N
35N
30N
25N
20N
15N
10N
5N
0
100E
110E
120E
130E
140E
150E
160E
170E
180
30
40


OLR Anomalies
60
40
20
0
−20
−40
−60
1JUN
1991
16JUN
1JUL
16JUL
1AUG
16AUG
1SEP
16SEP



Period (days)
64
32
16
−50
50
100
150
−100
0
OLR Anomalies
60
40
20
0
−20
−40
−60
Inactive
Inactive
Inactive
Active
Active
Active
Active
1JUN
1991
16JUN
1JUL
16JUL
1AUG
16AUG
1SEP
16SEP



Longitude-time cross section (12.5°~17.5°N) of 20~60 day filtered OLR (shading, Wm-2) and 20~60 day filtered 850 hPa vorticity (contour, 10-6s-1).

Triangles, stars and solid circles denote genesis locations of tropical depressions, tropical storms and typhoons between 7.5°N and 22.5°N respectively

Wheeler and Hendon (2004)

2-D circulation structure

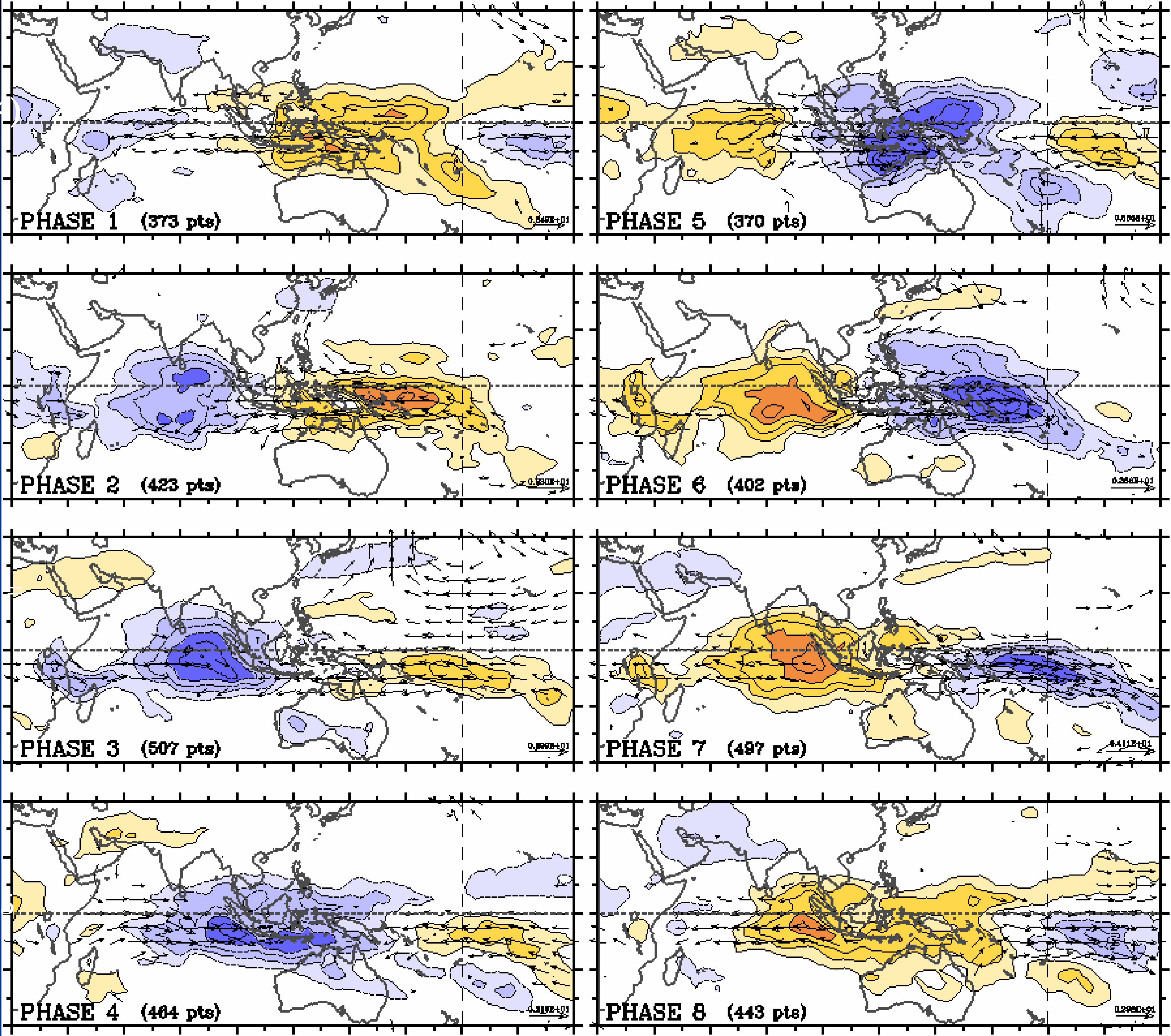
OLR

contour interval 4 Wm^{-2}

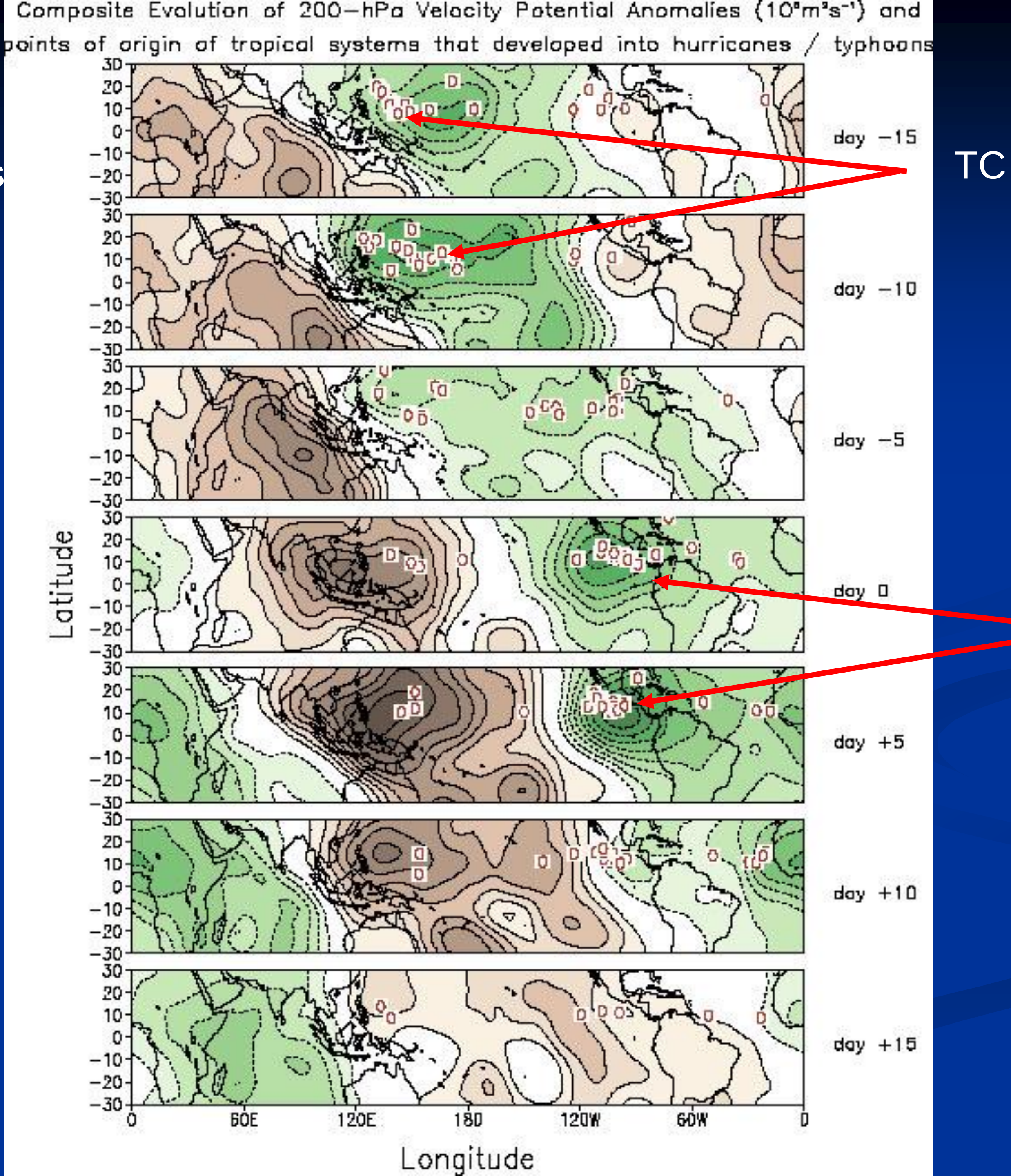
blue negative

850 hPa wind

Max vector = 4. ms^{-1}



From Higgins et al. 2000



MJO also affect the tropical cyclogenesis via monsoon trough

Overview

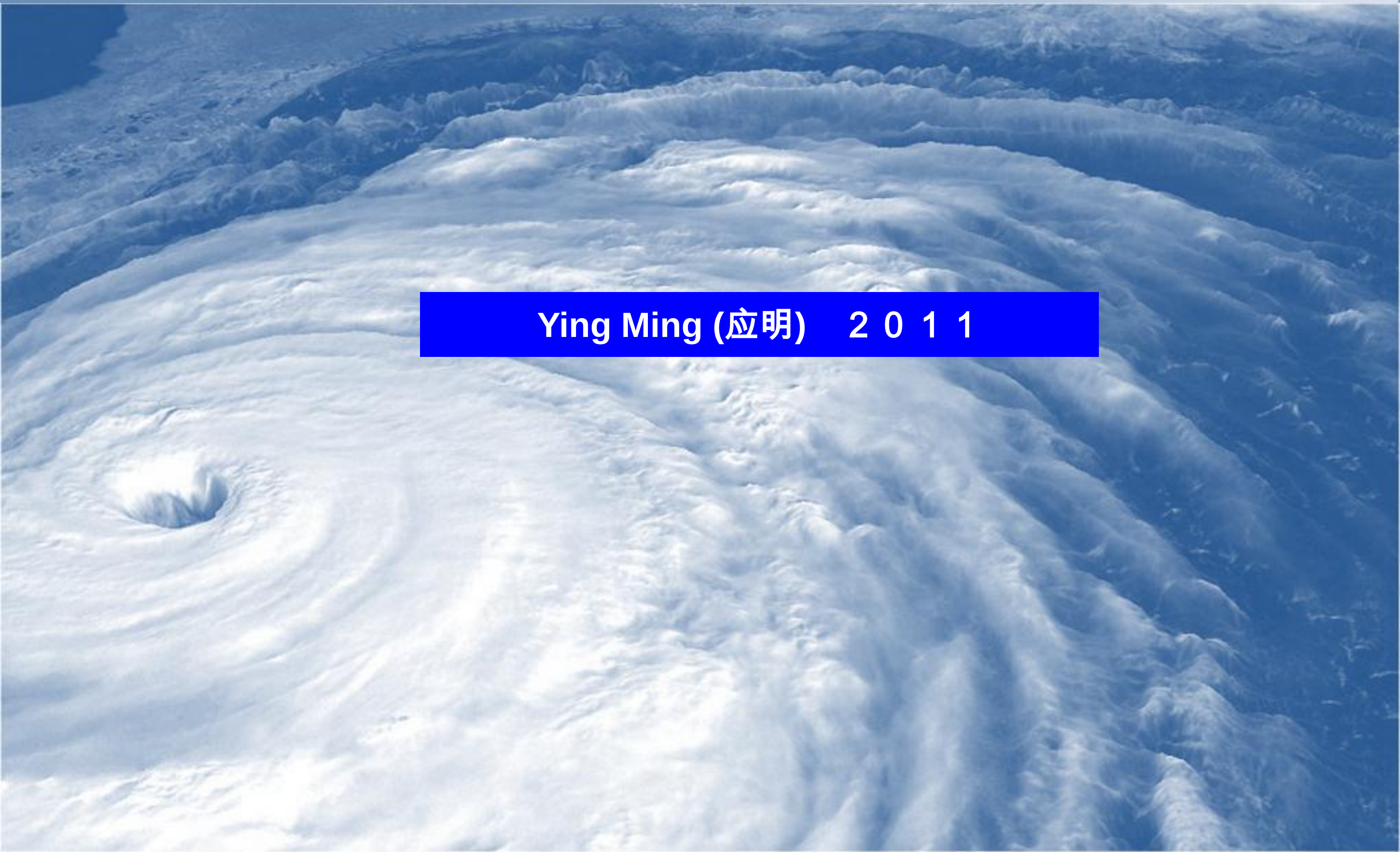
- Tropical ISO is a planetary-scale eastward propagating coupled atmosphere-ocean system, with a period of 30-60 days, influencing local weather (TC genesis)

- ✓ Clustering presumably results from the episodic occurrence of favorable large-scale environmental conditions (e.g., ISO, monsoon trough, providing strong low-level vorticity).

Outlines

1. Brief Review
2. LFV/ISO and Asian Summer Monsoon Onset
3. Tropical Vortex and BOB Monsoon Onset
4. Inertial Instability, ITCZ and SAM Onset
5. Monsoon, Subtropical Anticyclone and Tropical ISO
6. Intraseasonal modulation of tropical cyclogenesis
7. Extratropical Climate Impacts of Tropical Cyclone
8. Needs from the YOTC/AMY studies

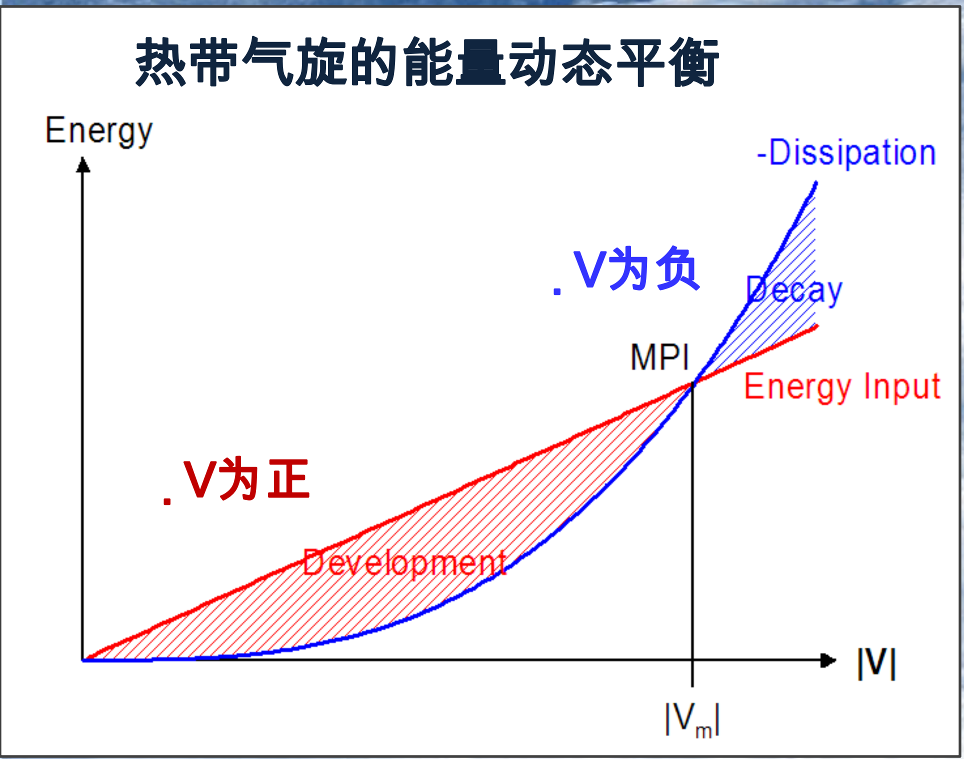
Extratropical Climate Impacts of Tropical Cyclone



Ying Ming (应明)　２０１１

海陆热力差异对TC活动的调控3

- 描述TC活动的**累积能量增长指数*AEI***



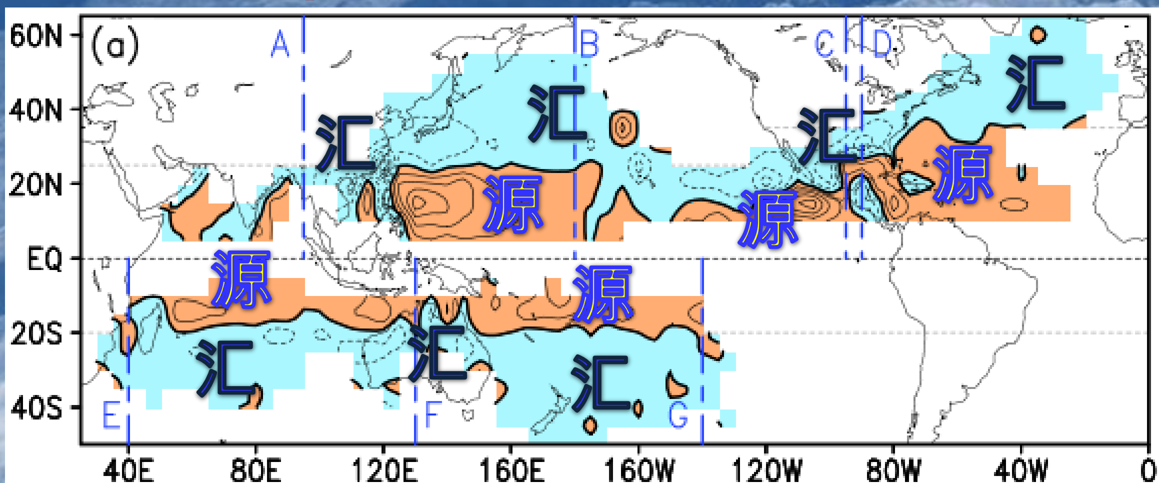
$$AEI_{(i,j)} = \frac{1}{K}\sum_{k=1}^{K}\sum_{n=1}^{N_k}\int_{t_1(n)}^{t_2(n)} \frac{\partial V_{kn}^2}{\partial \tau} dt$$

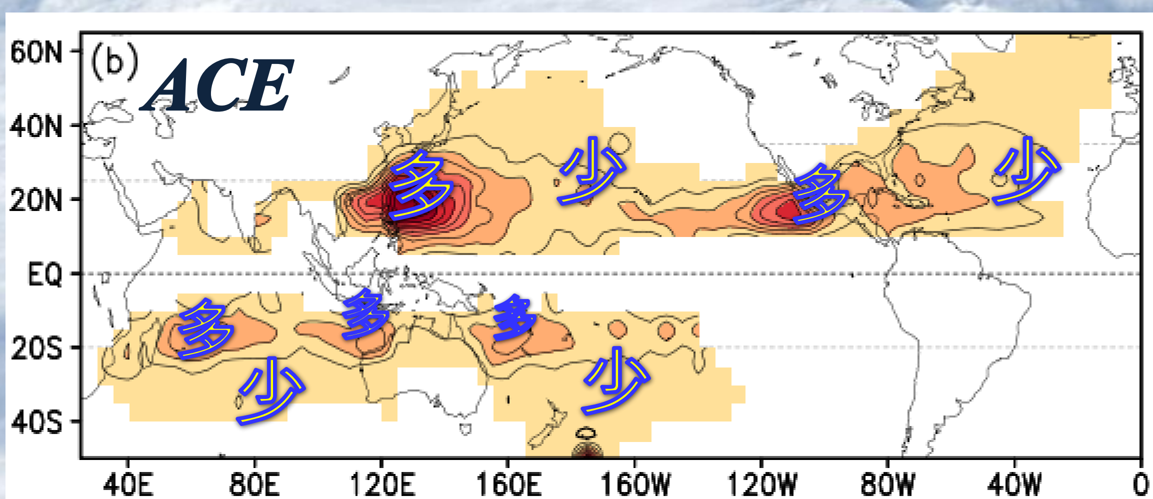
V ～ TC 能量收支变化

V	为近中心最大风速
t_1~t_2	为生命史长度
N	为TC数目
K	为年(季)数

*AEI*与一般TC活动指数比较

- ***AEI* 指数**





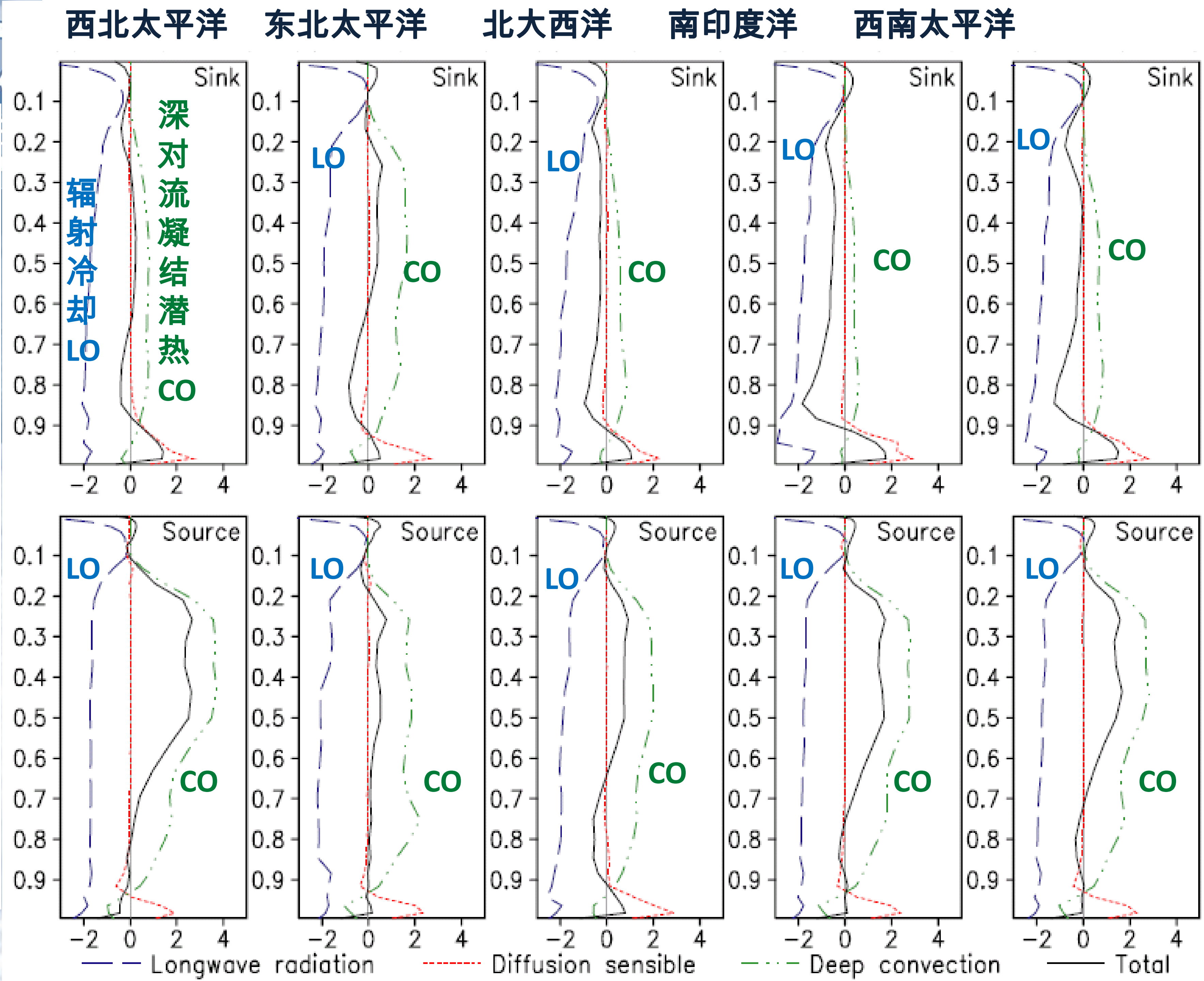
- 区分TC活动的能量源区和汇区
- 将TC活动与气候系统能量再分配联系起来
- 探讨TC与环境的相互作用

频数，强度，生命史的简单累计

$$SAI = \sum_{n=1}^{N}\sum_{t=0}^{T_n} a\left(V_{\max}\right)_{n,t}^{m}$$

HDP – Gray (1992)
ACE – Bell et al. (2000)
NTA – Kwon et al. (2007)
PDI – Emanuel (2005)
SAI – Wu et al. (2008)

汇区
↓
AEI
负



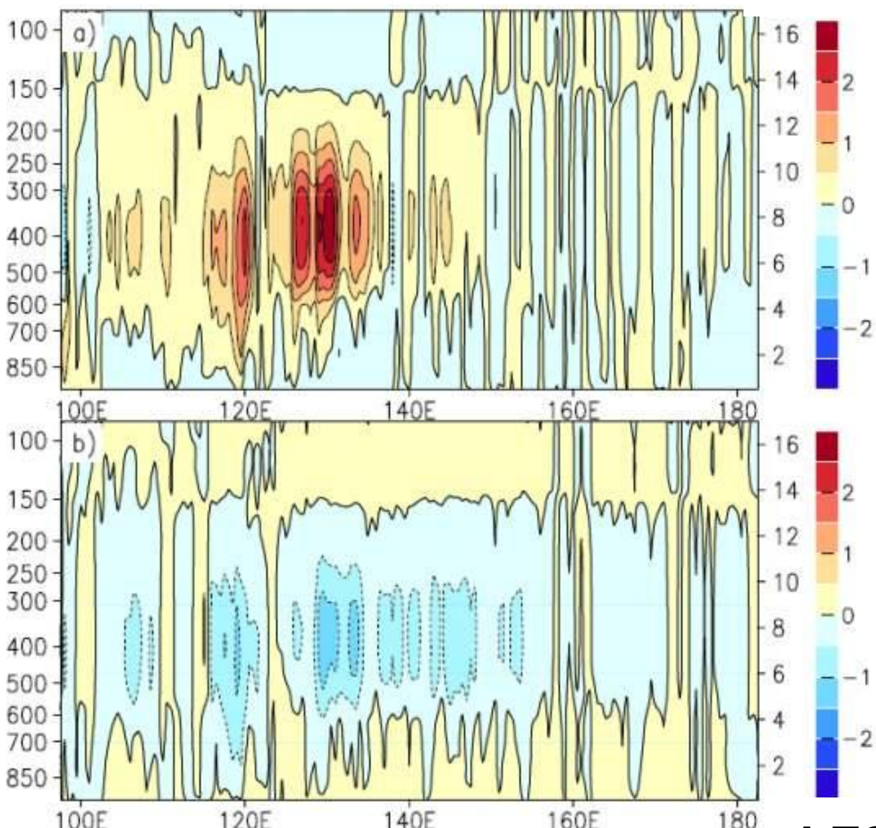
源区
↓
AEI
正

- **7–8月10°–27.5°N**

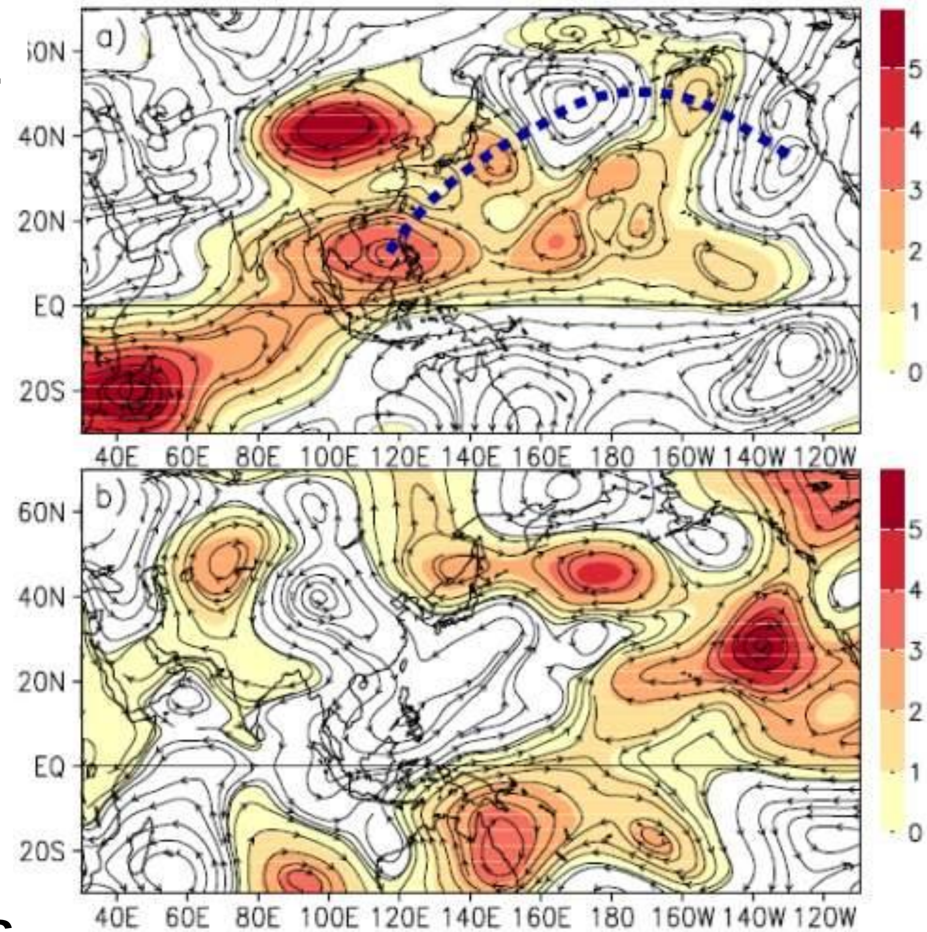
Stream function (200hPa) Anomaly

Latent Heating anomaly

MORE

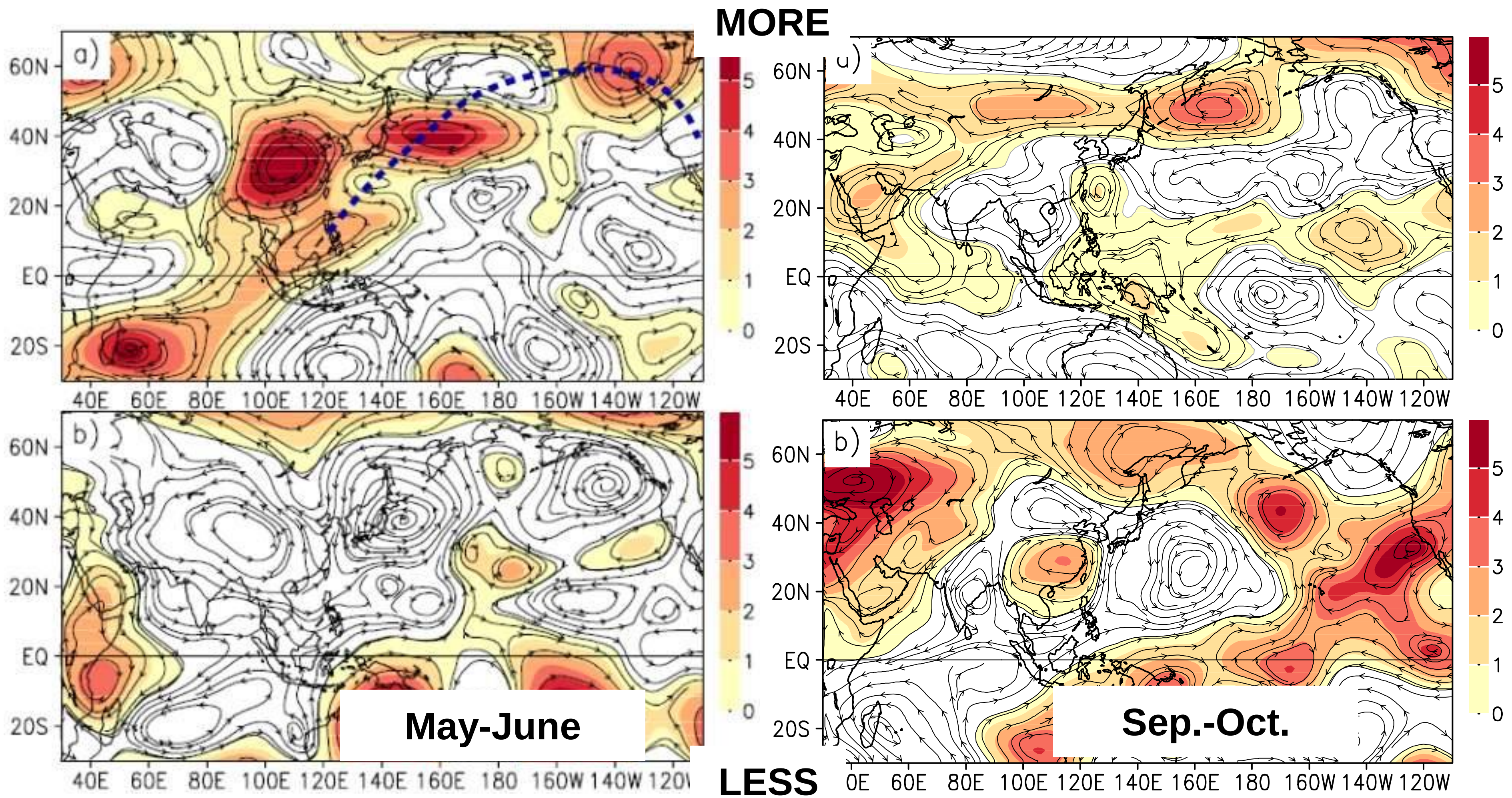


LESS



热带气旋活动的气候效应6

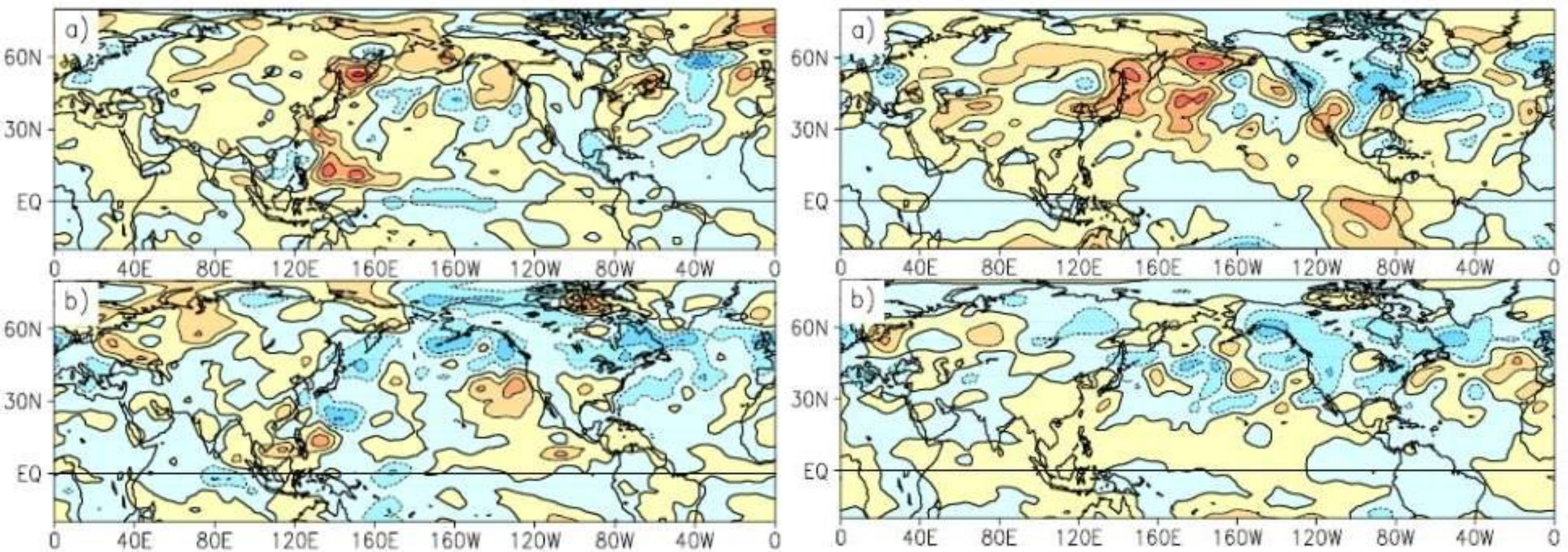
- 5–6月和9–10月200hPa Stream function (200hPa) Anomaly



August-October Eddy Kinetic Energy

8–10月850hPa、 200hPa扰动动能异常

MORE



LESS

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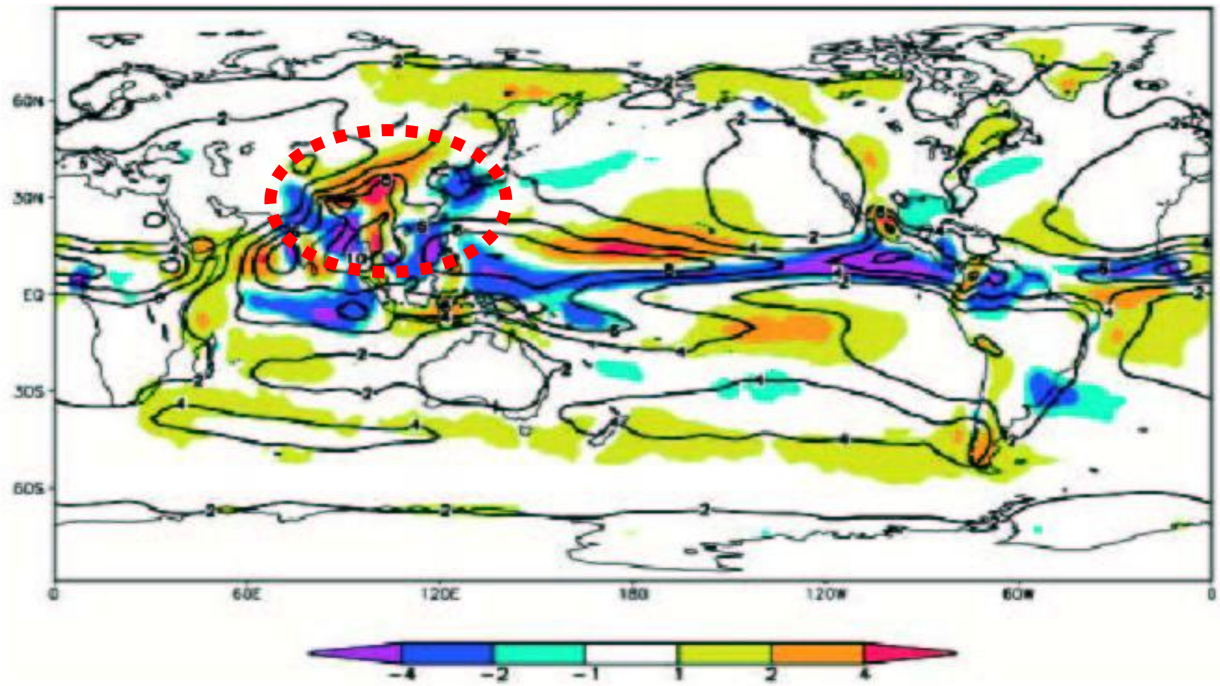
全球和区域业务数值预报中，对亚洲季风的模拟能力最差。



全球十个海气耦合模式模拟夏季降水误差分布（mmd^{-1}）

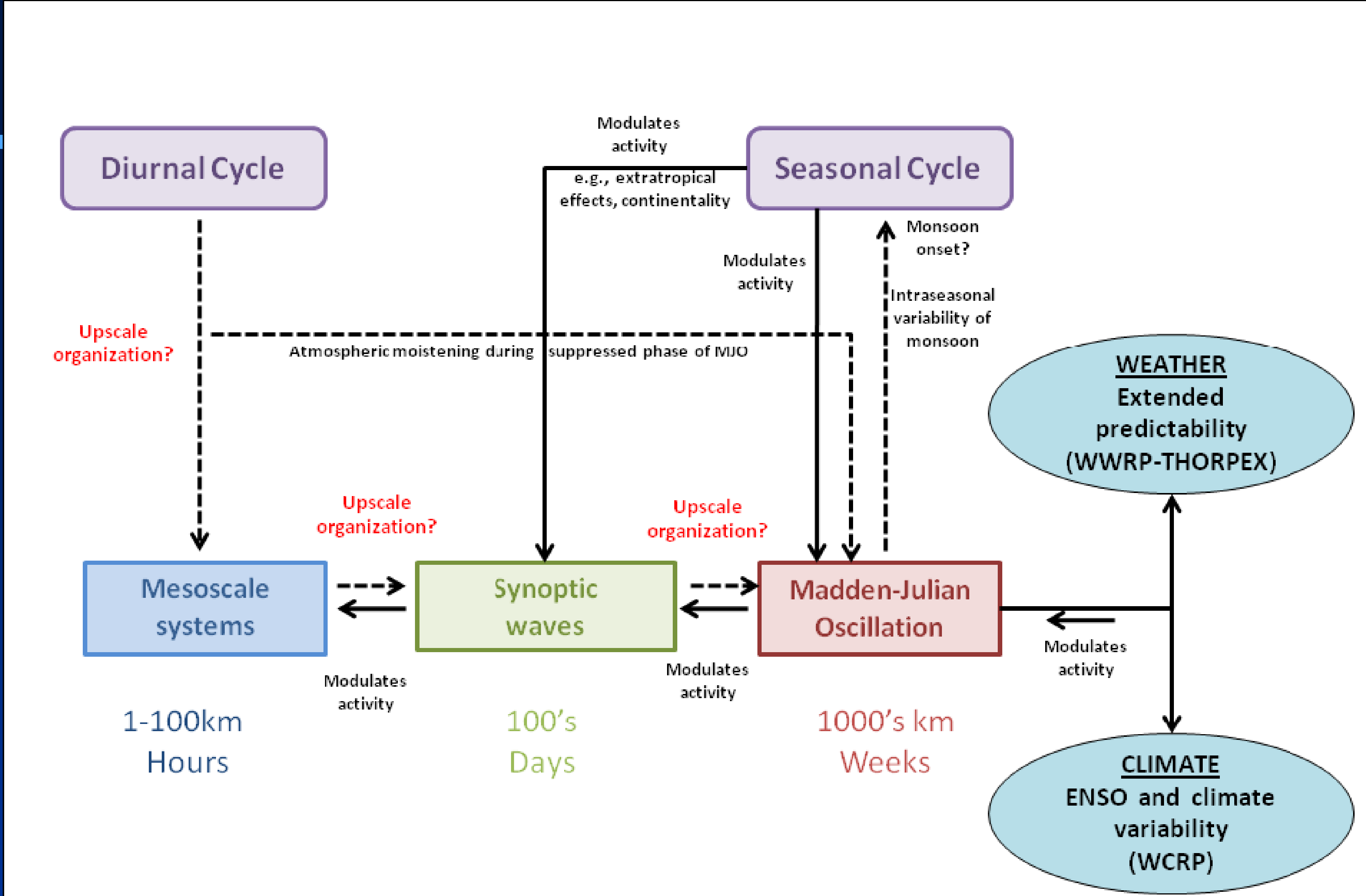


FIGURE 2. Primary temporal scales of tropical convection (diurnal cycle, seasonal cycle) and the primary discrete spectrum of spatial scales [mesoscale convective systems (MCS) , synoptic waves, and the MJO]. The discrete spectum exhibits a further level of spectral coherence: i) mesoscale systems are families of cumulonimbus; ii) synoptic waves are families of cumulonimbus and MCS); MJO is and envelope of superclusters, MCS, and cumulonimbus). Understanding the upscale effects of convective organization is a crucial element of the monsoons, and lower-frequency aspects such as ENSO and climate variability. (Moncrieff et al., 2011, BAMS)

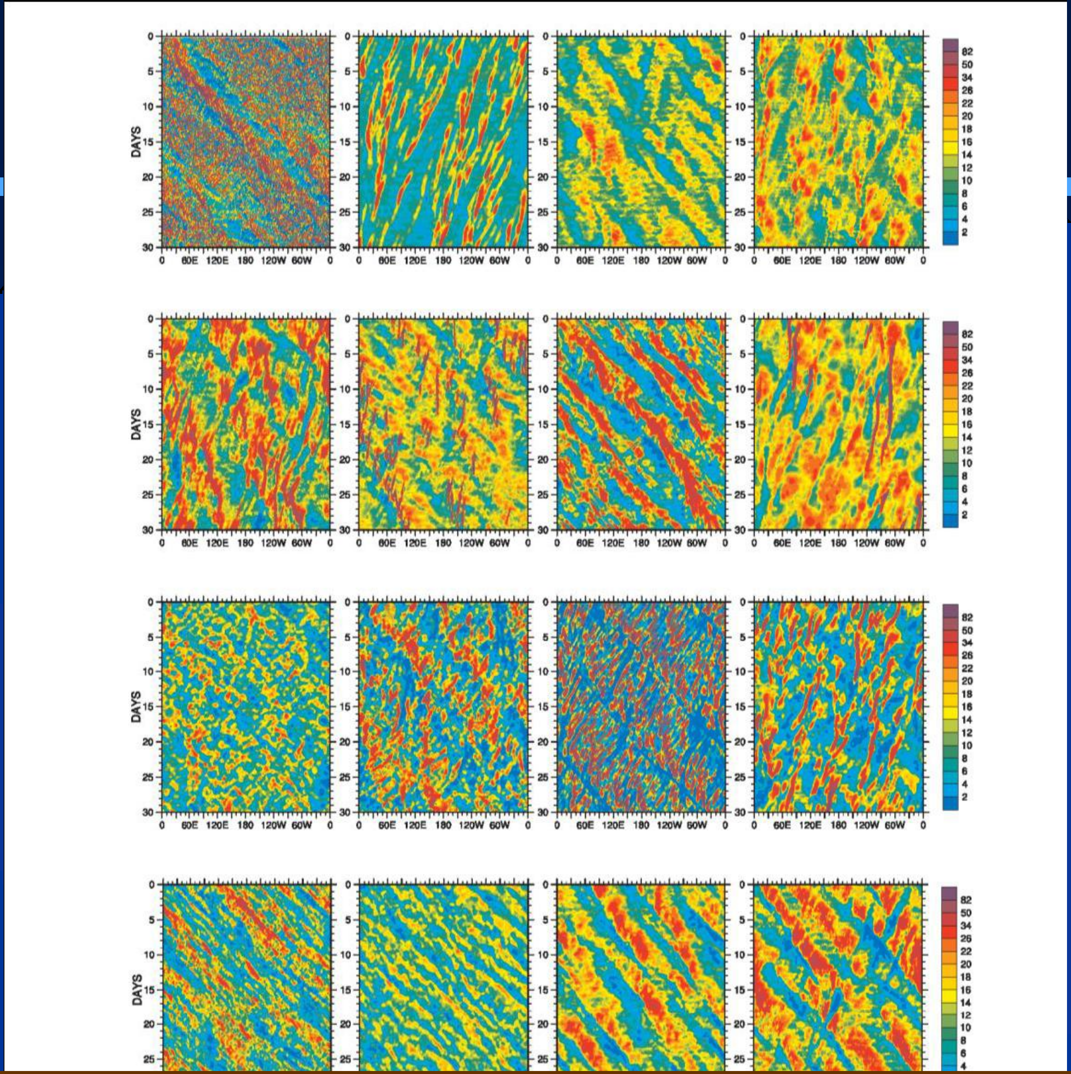


FIGURE 3. Hovmoeller plots of equatorial precipitation averaged from -5 to +5 latitude (mm/day) from all models in the Aqua Planet Experiment (APE). the top left-hand corner is from (NICAM) global cloud-system resolving simulation with a 7 km computational mesh.

This lack of agreement between climate models is thought to stem from deficiencies in the convective parameterizations. (Moncrieff et al., 2011, BAMS; Waliser et al. 2010.)

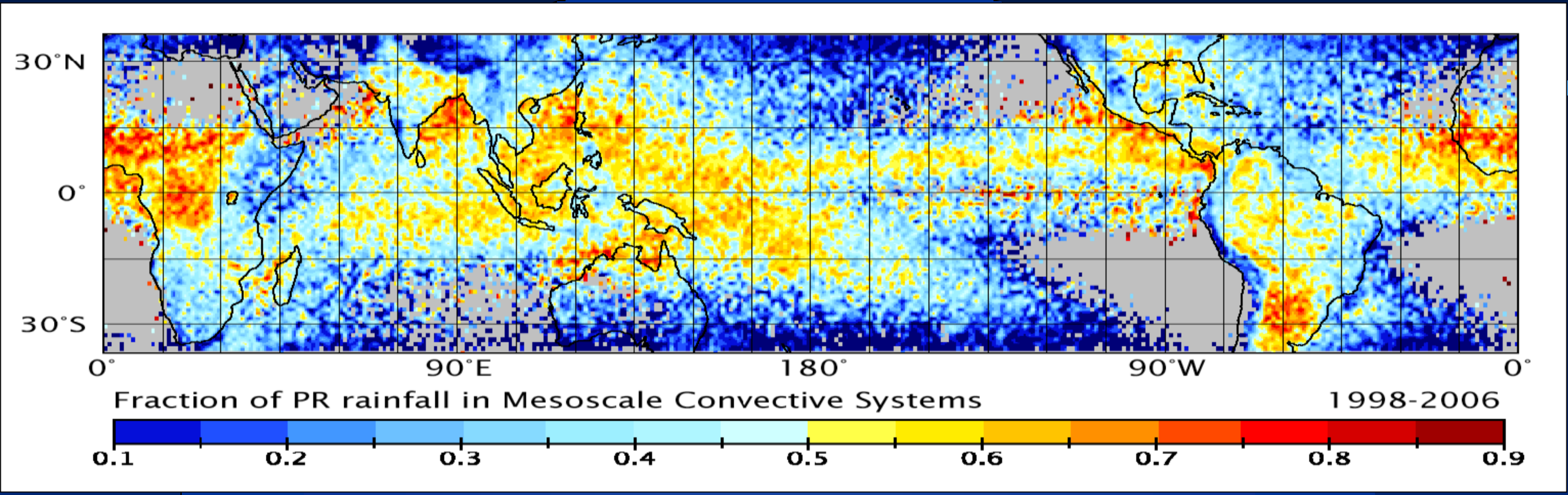


FIGURE 5. Fraction of estimated rainfall from precipitation features ≥ 100 km in maximum dimension as measured by the TRMM precipitation radar (PR) from January 1998 through December 2006 using the methodology of Nesbitt et al. (2006).

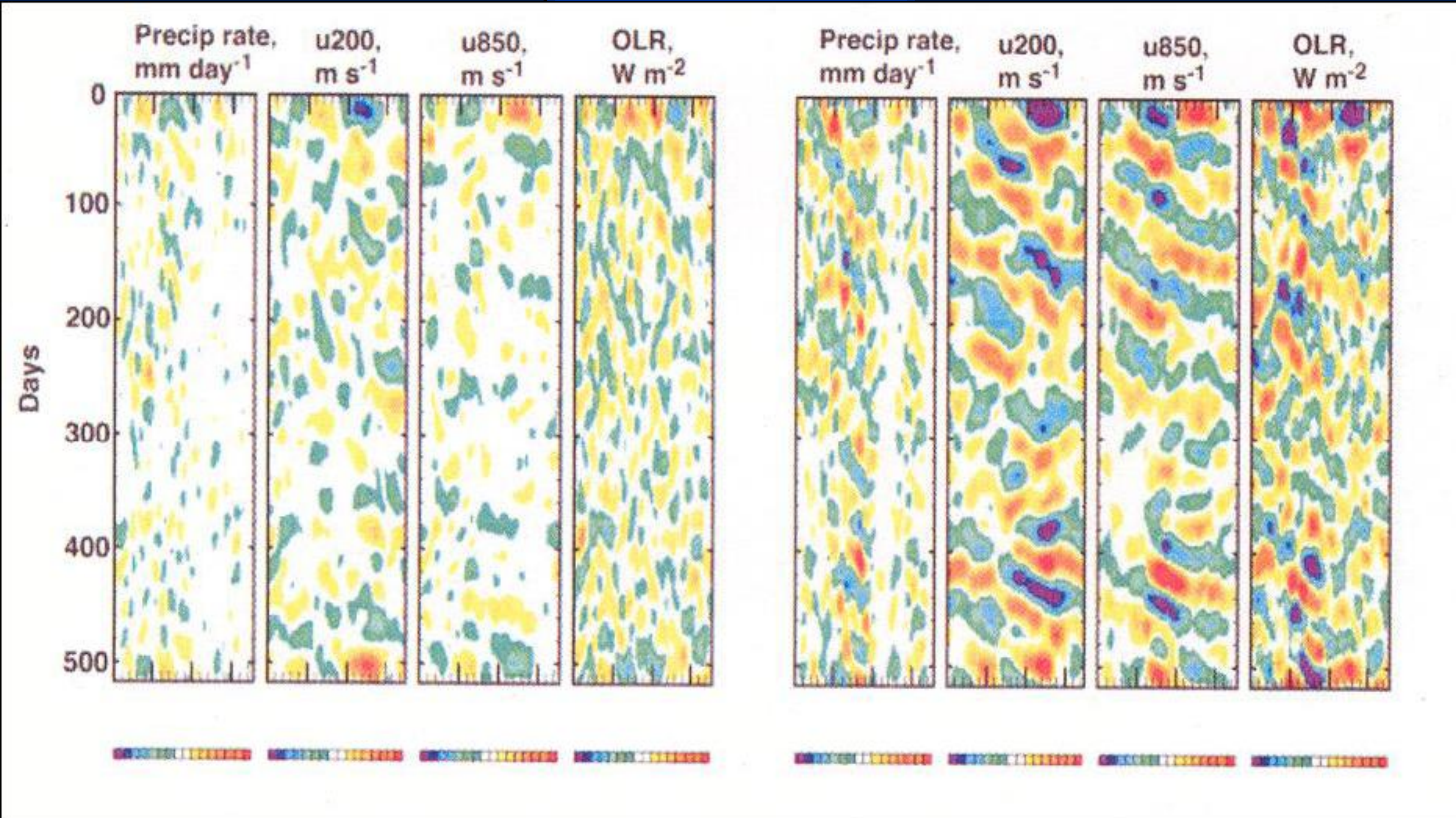


FIGURE 8. Left, weak MJO activity in the standard version of the Community Atmospheric Model (CAM). Right, strong MJO activity occurs in the version of CAM (SP-CAM) applying superparamerization. [Courtesy: Khairoutdinov et al. 2005].

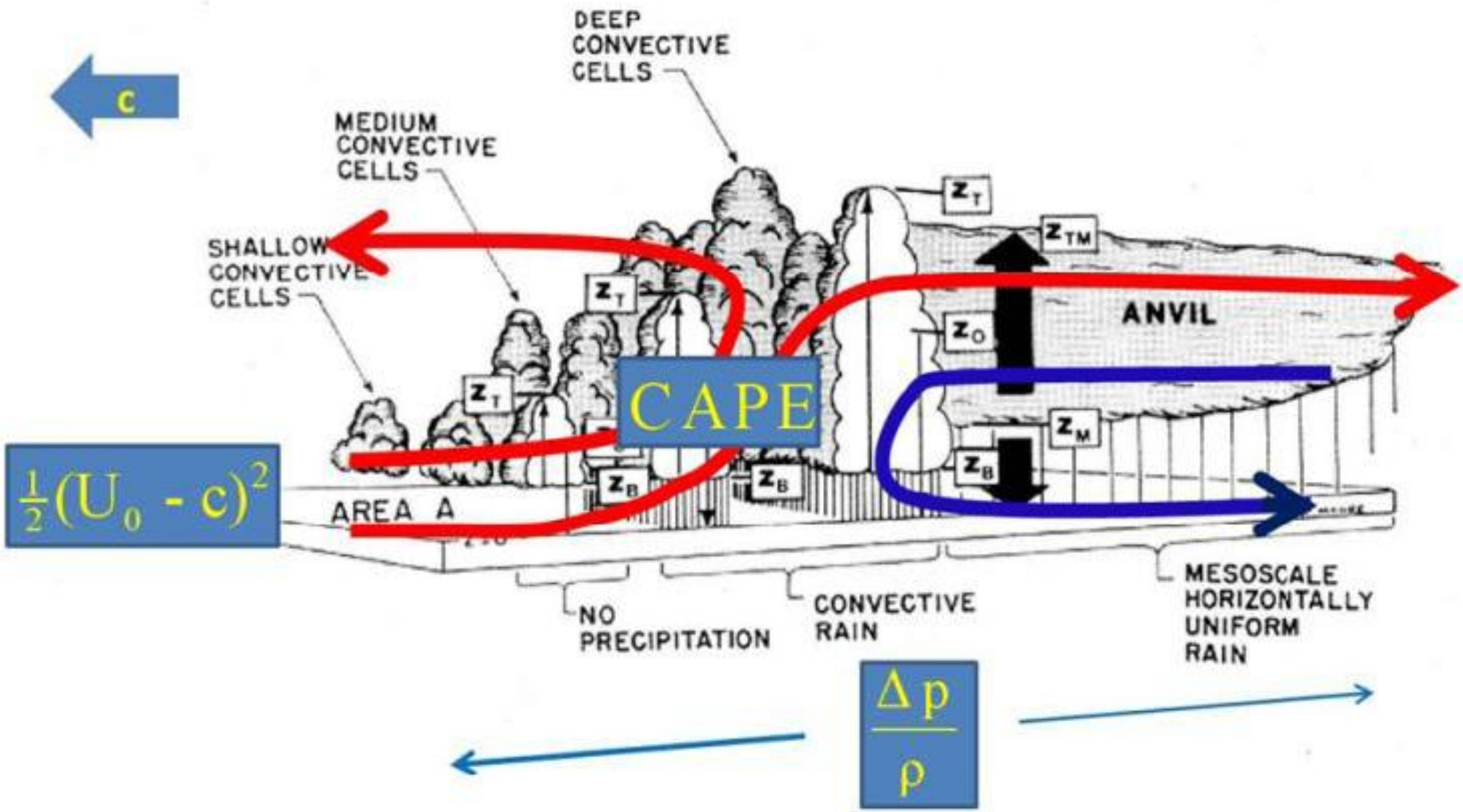
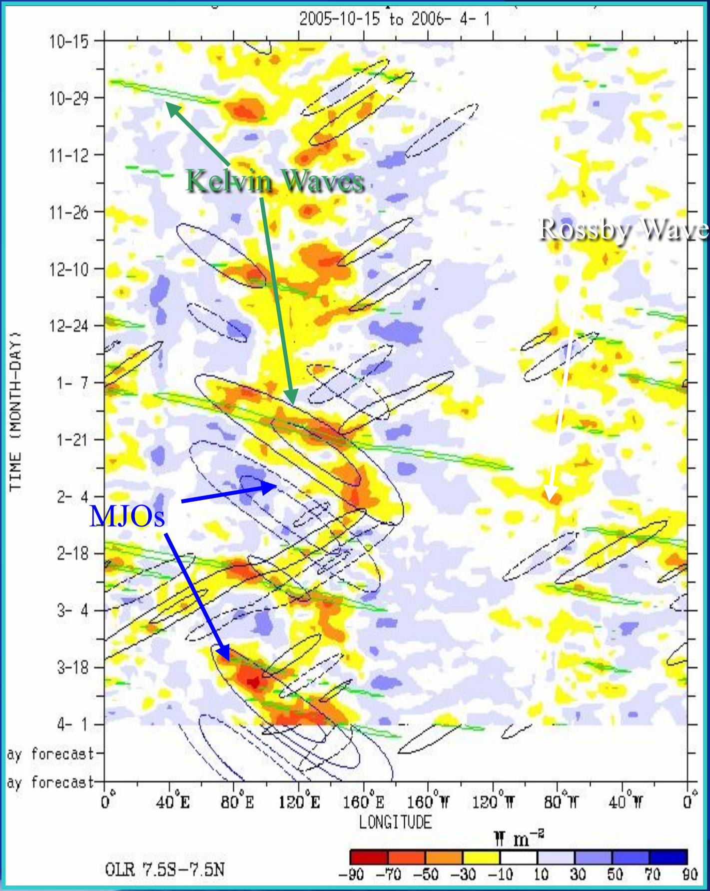


FIGURE 7. Slantwise overturning (Moncrieff 1992) identified by red/ blue trajectories for upflow/ downflow , respectively, superimposed on the Houze (2004) conceptual model of an MCS propagating right-to-left at speed c. The three forms of energy involved in slantwise overturning (thermodynamic, kinetic, and the work done by the pressure gradient) are in the blue inserts.

Our shortcomings in tropical convection severely limit the representation of key physics in weather & climate models

- **Diurnal cycle** - strongest "forced" signal in the climate system.
- Synoptic waves and **easterly waves**, including development & evolution of **hurricanes and Tropical cyclones**
- **Madden-Julian Oscillation (MJO)** and other large-scale convectively-coupled waves
- **monsoon variability**, including onset and break activity.
- **Tropical mean state**, including **ITCZ** and distributions of rainfall over oceans & continents

Winter 2005-6



Dominant Convectively-Coupled Tropical Waves Projected onto OLR Anomalies. Wheeler and Weickmann, 2001

1. What is the critical scale L_c~10km?

γ: 2-20km; β: 20-200km; α: 200-2000km

2. Relative importance of slantwise convection ~CAPE in tropics and in extratropics

3. Can the effects of slantwise convection be parameterized?
-wind shear; wave propagation; pressure gradient etc……

4. Mechanism studies are needed

-ocean~ MJO/ISO

-modulation of land-sea distribution on a-s interaction and TC formation……

Thank You !