The Diurnal Cycle of Tropical and Monsoon Convection

Richard H. Johnson

Colorado State University

(Andy Newman , Brian McNoldy, and Paul Ciesielski)

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T. Ushiyama

Why do we care about the diurnal cycle?

- Diurnal cycle is of fundamental importance for weather and climate
- "Diurnal cycle is rectified onto intraseasonal [and longer] time scales…and is poorly represented in global models" (Sperber and Yasunari 2006)
- For example, modeled maritime continent heat source without diurnal cycle is too weak (Neale and Slingo 2003)

Characteristics of the Diurnal Cycle

- General behavior: afternoon maximum over land, nighttime maximum over ocean; important exceptions over land and ocean
- Migrating/propagating signals downstream of mountain ranges and seaward from coastlines
- Over ocean, amplitude of diurnal cycle is greater for larger, more-organized convective systems than for isolated convection
- Semidiurnal cycle observed at some tropical locations

Mechanisms of the Diurnal Cycle

- Thermodynamic processes that affect static stability
  - Diurnal cycle of surface heating
  - Cloud-radiative effects
  - Diurnal variation in boundary-layer moisture
- Processes that affect PBL convergence
  - Sea and land breezes
  - Mountain/valley flows
  - Wind variations at top of boundary layer
  - Horizontal gradients in radiative/heating cooling
  - Vertical momentum mixing

TRMM 3B42* 10-year Mean Rainfall

1998-2007

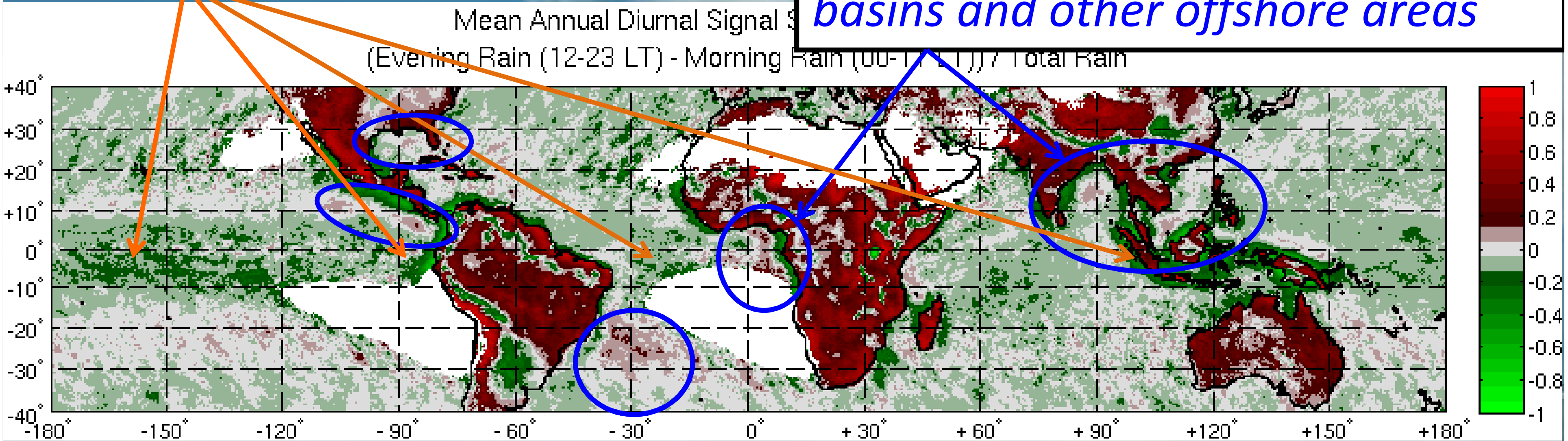
- *Much of world's heaviest rainfall in the tropics and monsoon regions occurs within ITCZs/SPCZ, and also along coastlines ⇒ diurnal cycle is important*

* Geostationary IR precipitation estimates adjusted by optimal combination of TRMM, SSMI, AMSR, AMSU, and other microwave measurements scaled to match monthly rain gauge observations

Normalized Amplitude, Mean Diurnal Cycle of Annual Rainfall (1998-2007)

Nocturnal maxima generally over oceans, along coastlines

Afternoon/evening maxima over land…but also interior ocean basins and other offshore areas



[Evening (12-23 LT) minus Morning (00-11 LT) Rain]

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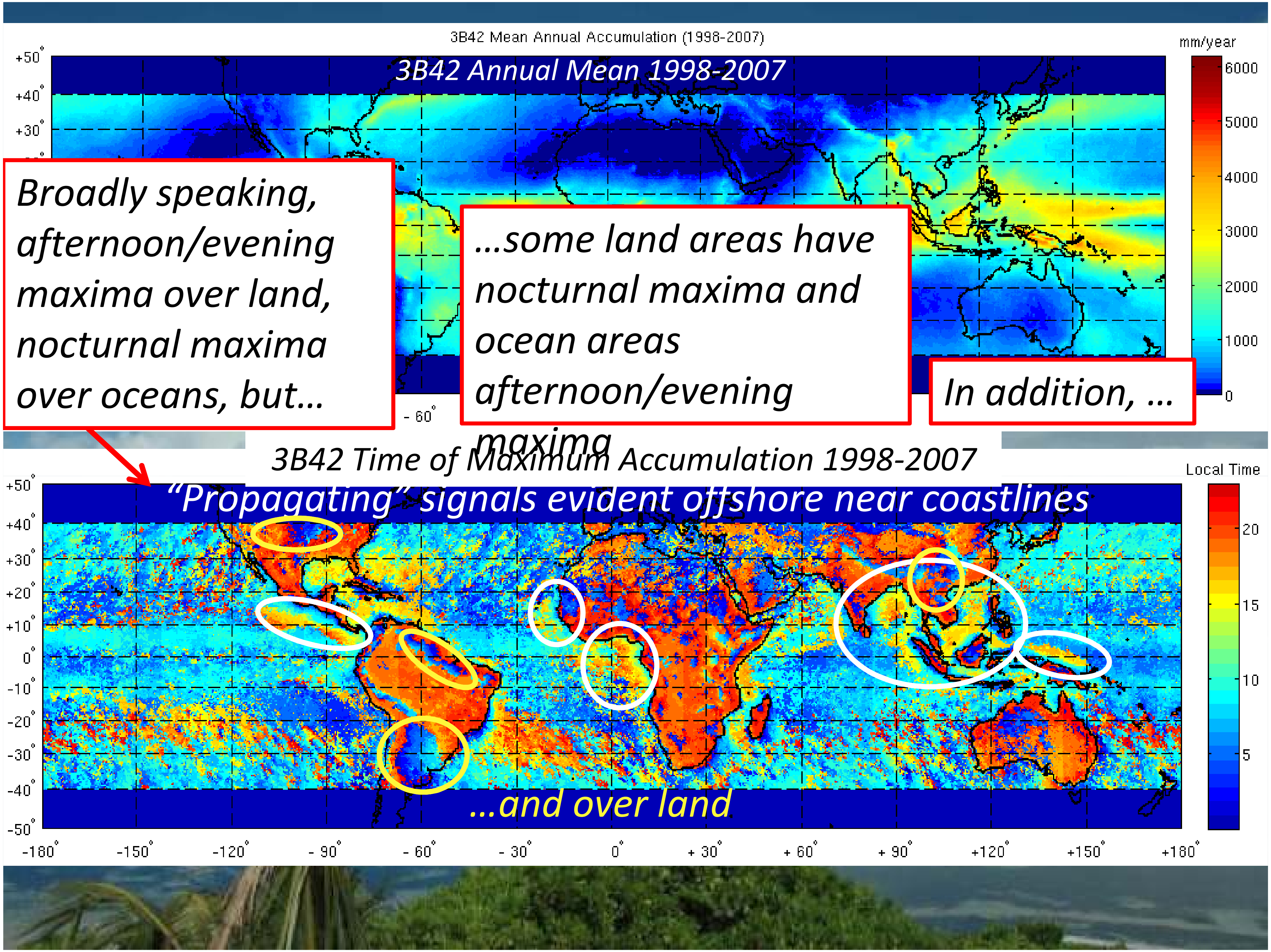
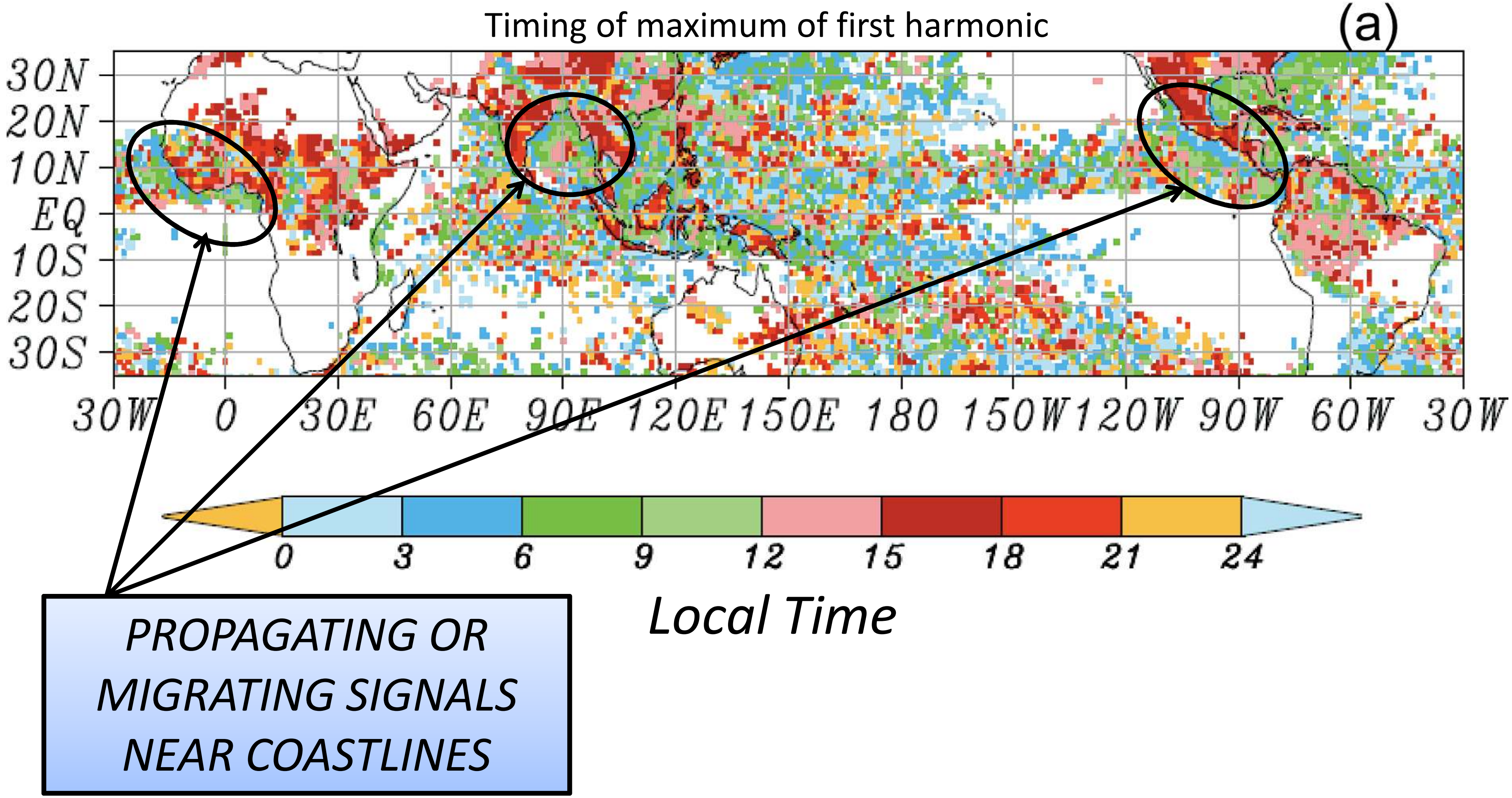
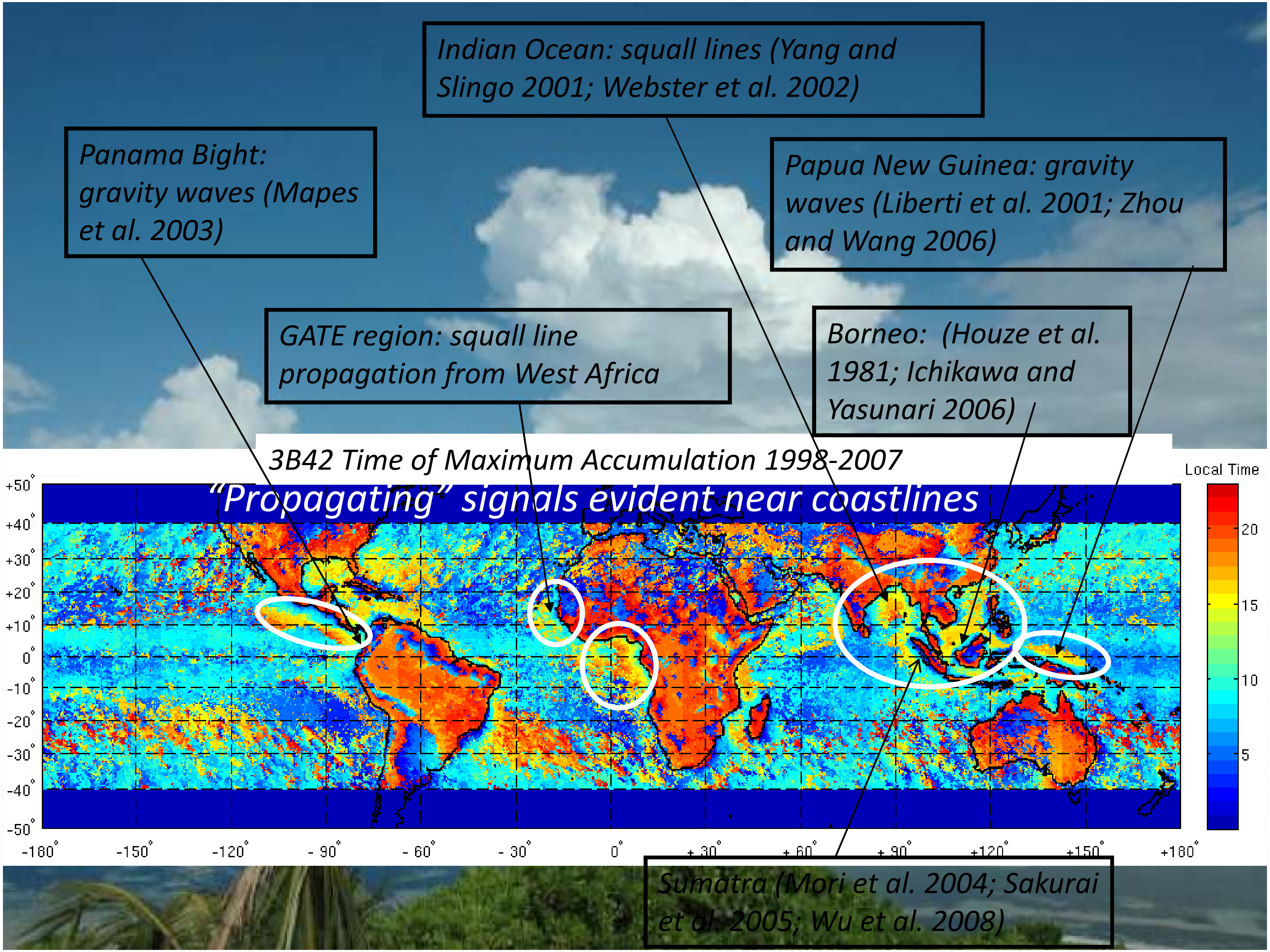
[Annual Mean Rainfall]

(excluding areas with < 100 mm rainfall per year)


3B42 Mean Annual Accumulation (1998-2007)
3B42 Annual Mean 1998-2007
mm/year
6000
5000
4000
3000
2000
1000
0
Broadly speaking, afternoon/evening maxima over land, nocturnal maxima over oceans, but…
…some land areas have nocturnal maxima and ocean areas afternoon/evening maxima
In addition, …
3B42 Time of Maximum Accumulation 1998-2007
"Propagating" signals evident offshore near coastlines
…and over land
Local Time
20
15
10
5
+50°
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
-50°
-180°
-150°
-120°
- 90°
- 60°
- 30°
0°
+ 30°
+ 60°
+ 90°
+120°
+150°
+180°

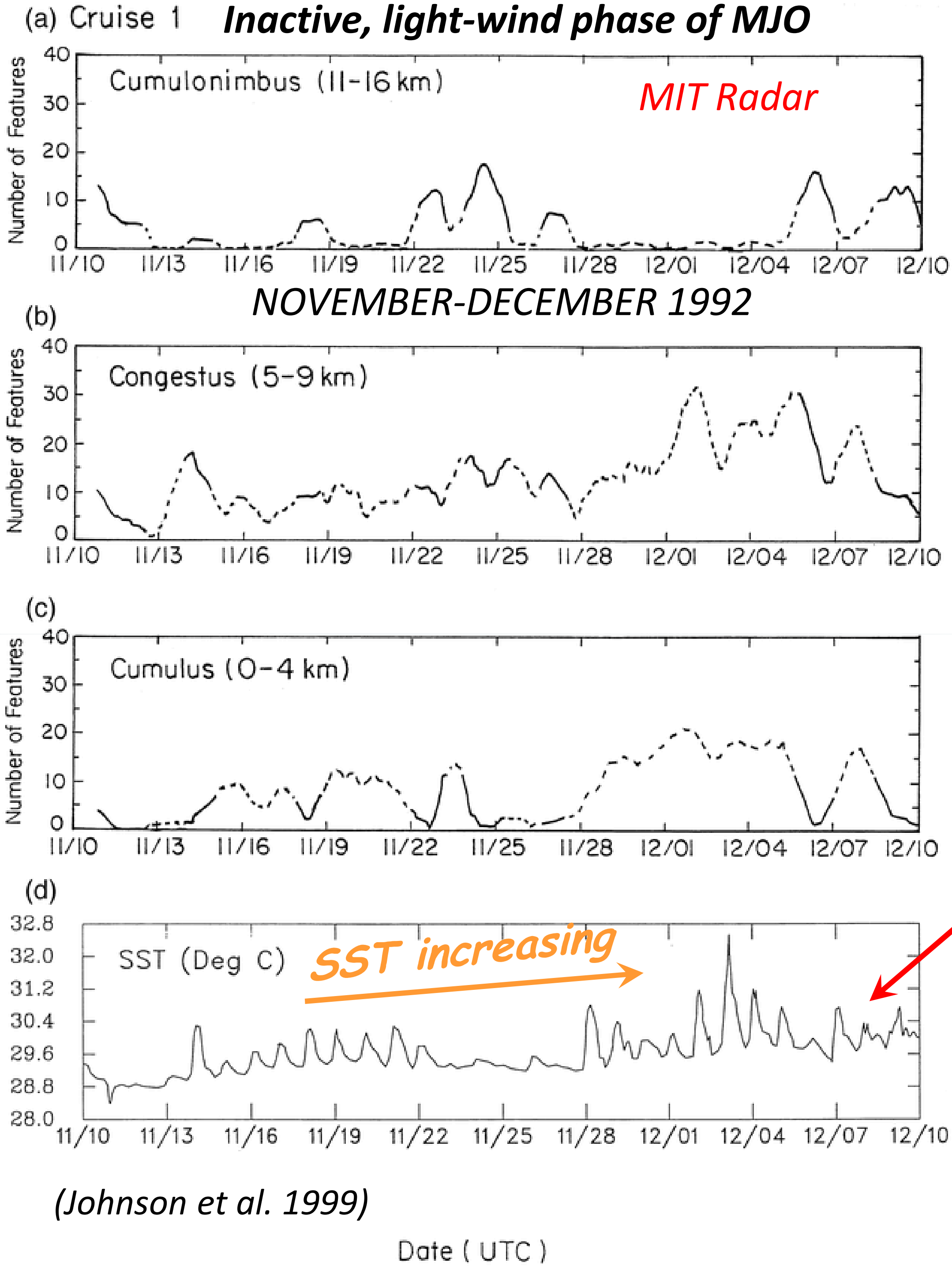
- Similar results obtained by Takayabu et al. (2008) using TRMM PR data



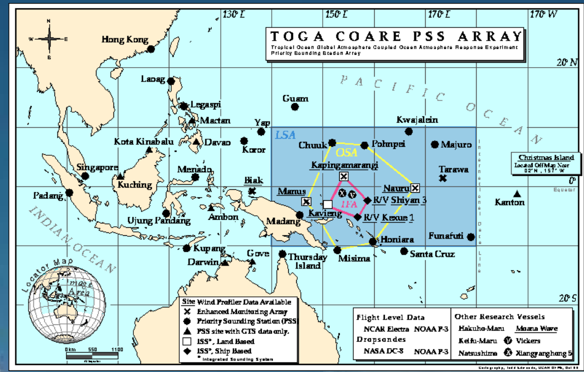

Indian Ocean: squall lines (Yang and Slingo 2001; Webster et al. 2002)
Panama Bight: gravity waves (Mapes et al. 2003)
Papua New Guinea: gravity waves (Liberti et al. 2001; Zhou and Wang 2006)
GATE region: squall line propagation from West Africa
Borneo: (Houze et al. 1981; Ichikawa and Yasunari 2006)
3B42 Time of Maximum Accumulation 1998-2007
"Propagating" signals evident near coastlines
Local Time
20
15
10
5
+50°
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
-50°
-180°
-150°
-120°
- 90°
- 60°
- 30°
0°
+ 30°
+ 60°
+ 90°
+120°
+150°
+180°
Sumatra (Mori et al. 2004; Sakurai et al. 2005; Wu et al. 2008)

Diurnal Cycle over Open Ocean

- Over the majority of the tropical open ocean areas, precipitation is nocturnal
- An important exception: light-wind conditions over tropical oceans where a shallow diurnal warm layer develops in the upper ocean
- Example: western Pacific during the inactive phase of the MJO, as seen during 1992-93 TOGA COARE; also during MISMO 2006



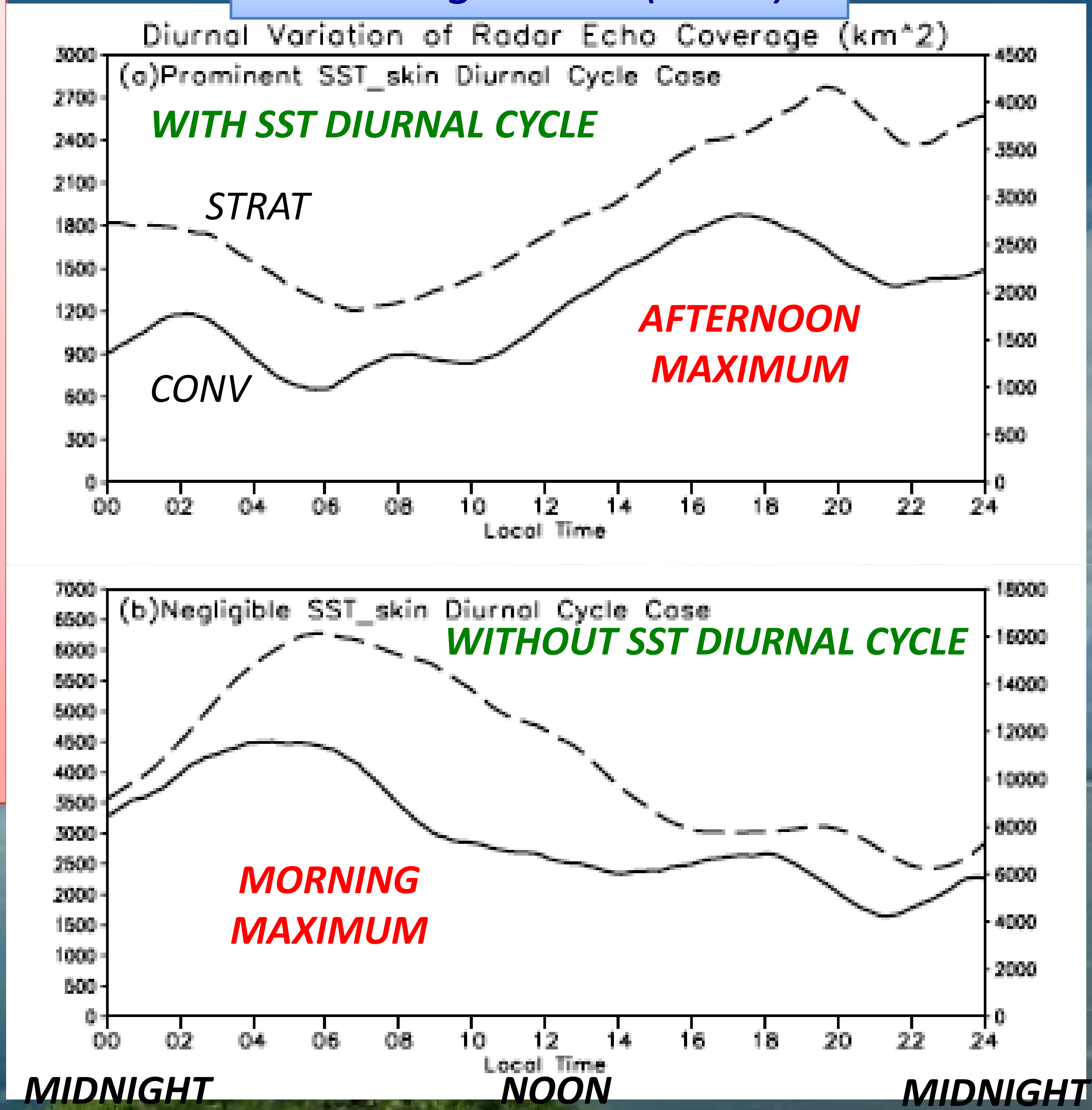
(Johnson et al. 1999)



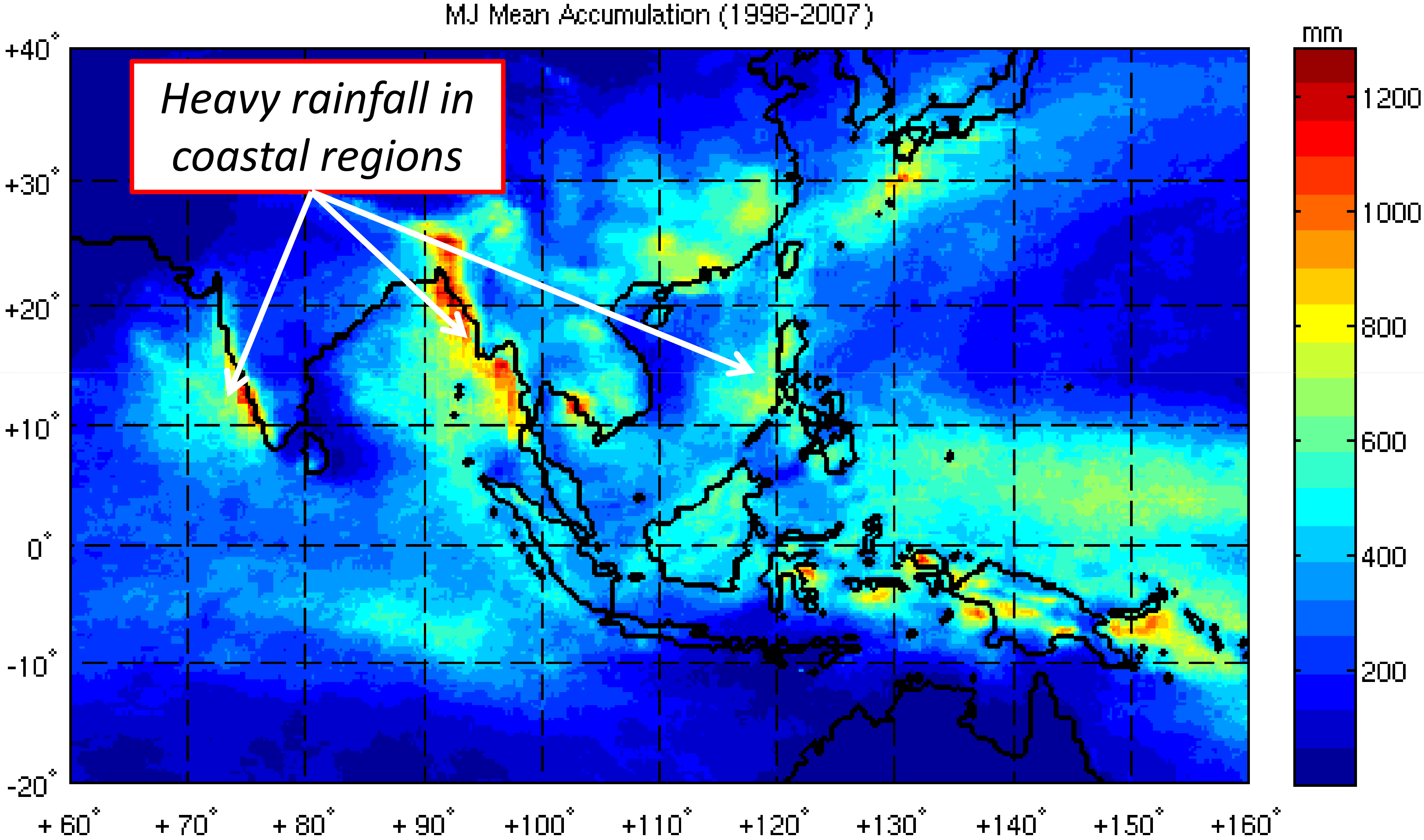
- Gradual increase in *precipitating* cumulus and congestus cloud populations
- SST exhibits strong diurnal signal
- Afternoon maximum in shallow cu and cg on these days

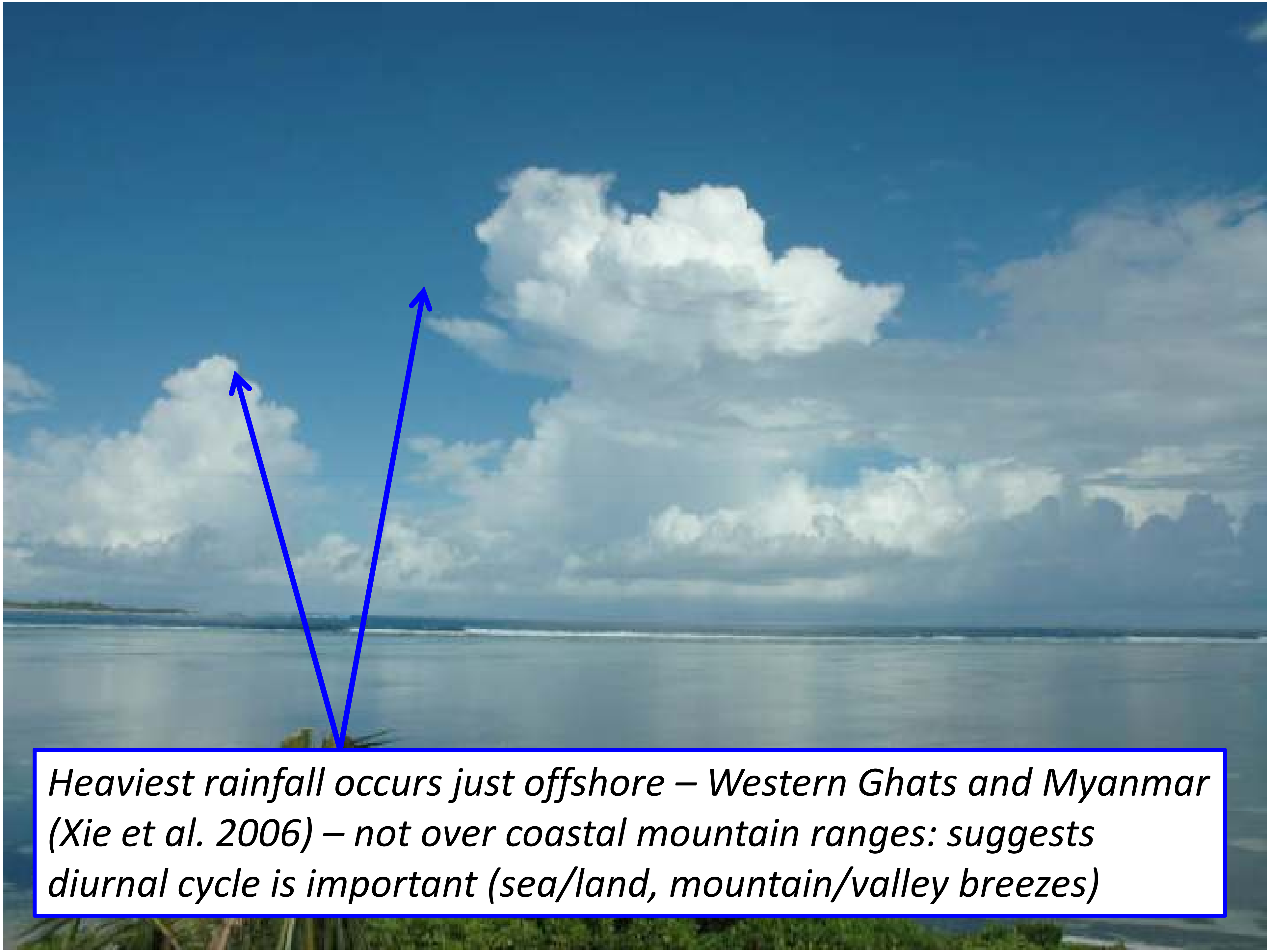
Yasunaga et al. (2008)

Diurnal variation in radar echo coverage during MISMO 2006: afternoon maximum in light-wind conditions



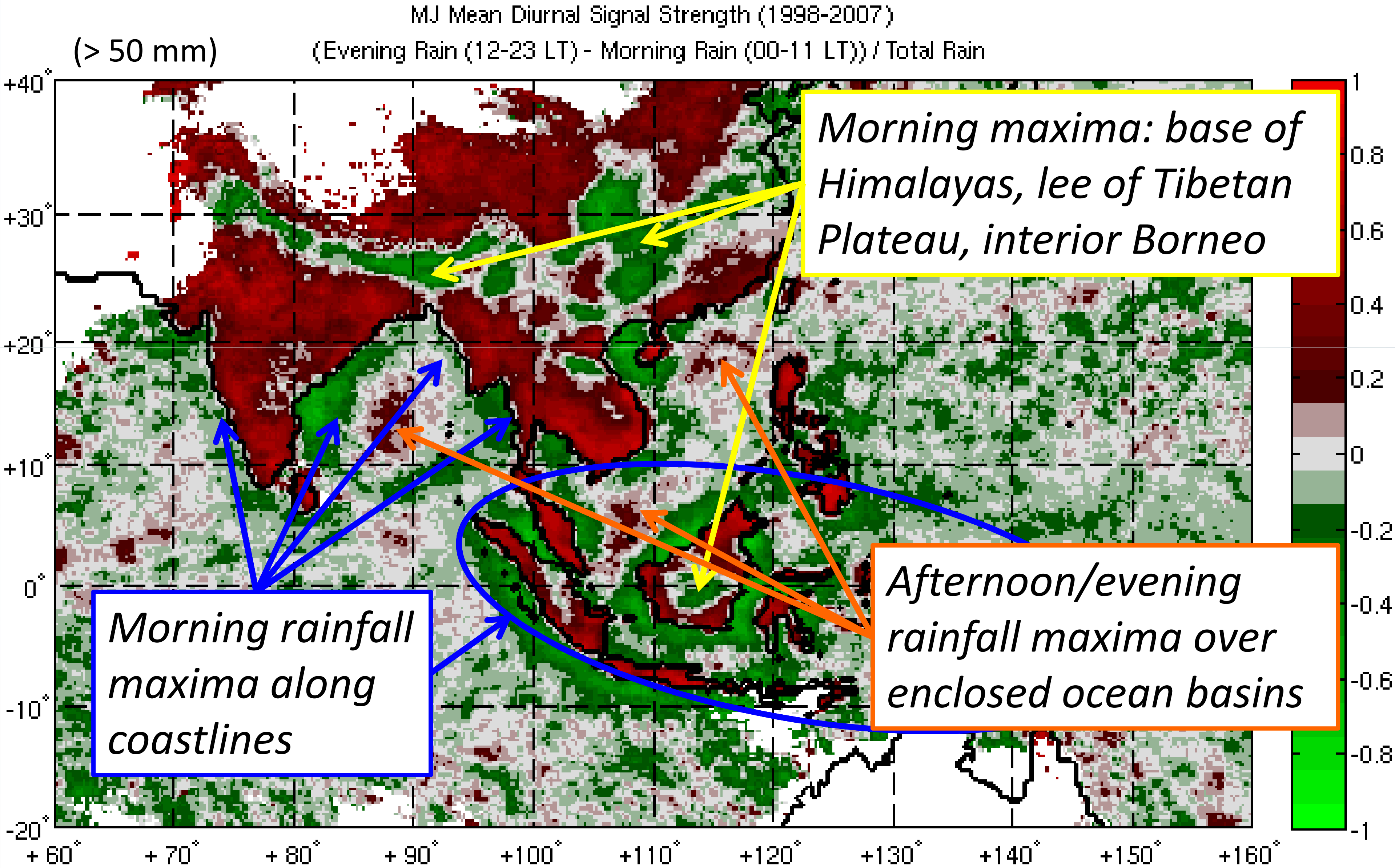
Ten-year (1998-2007) May-June Mean Rainfall





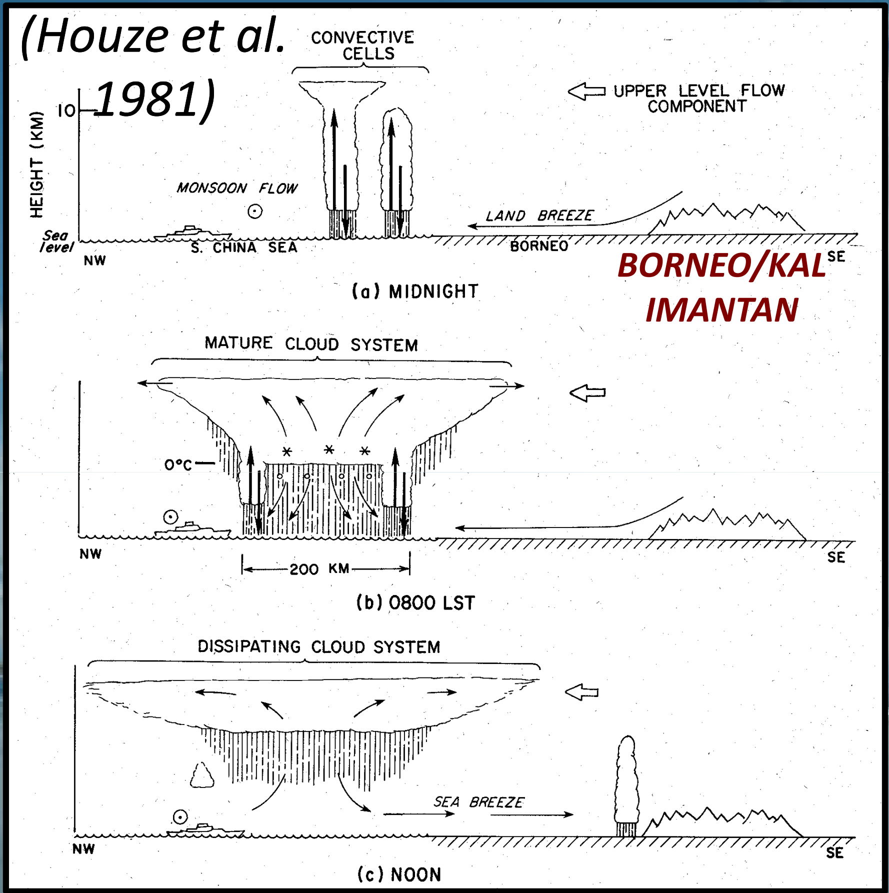
Heaviest rainfall occurs just offshore – Western Ghats and Myanmar (Xie et al. 2006) – not over coastal mountain ranges: suggests diurnal cycle is important (sea/land, mountain/valley breezes)

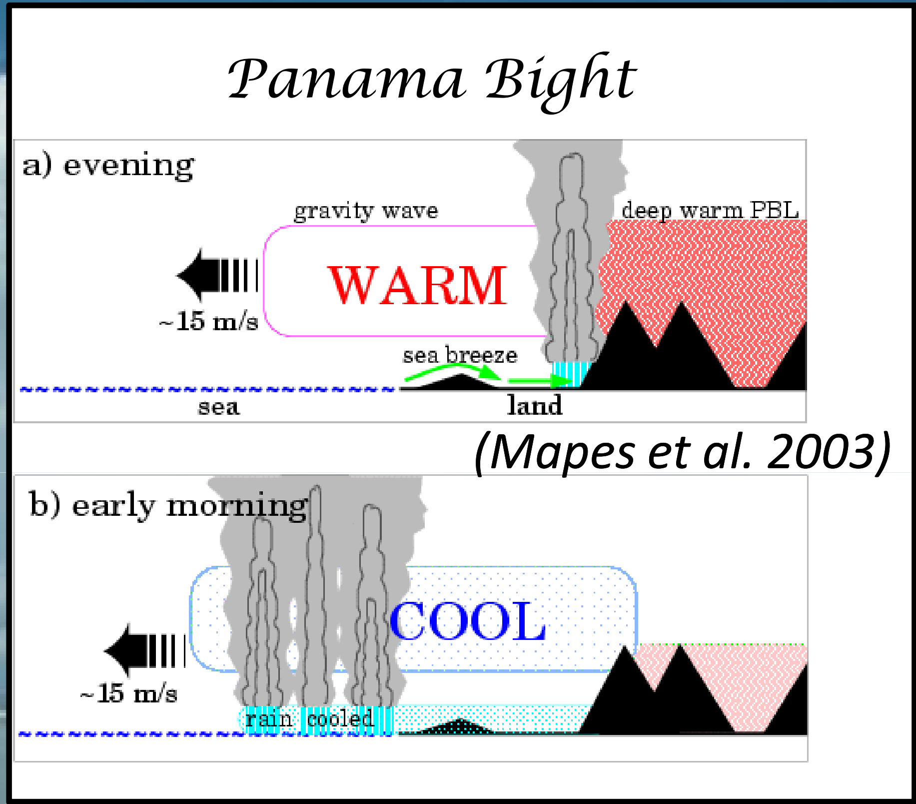
Normalized Amplitude, Mean Diurnal Cycle of May-June Rainfall (1998-2007)



Explanations for Nocturnal Coastal Convection

1. *Land Breeze*
2. *Gravity Waves*

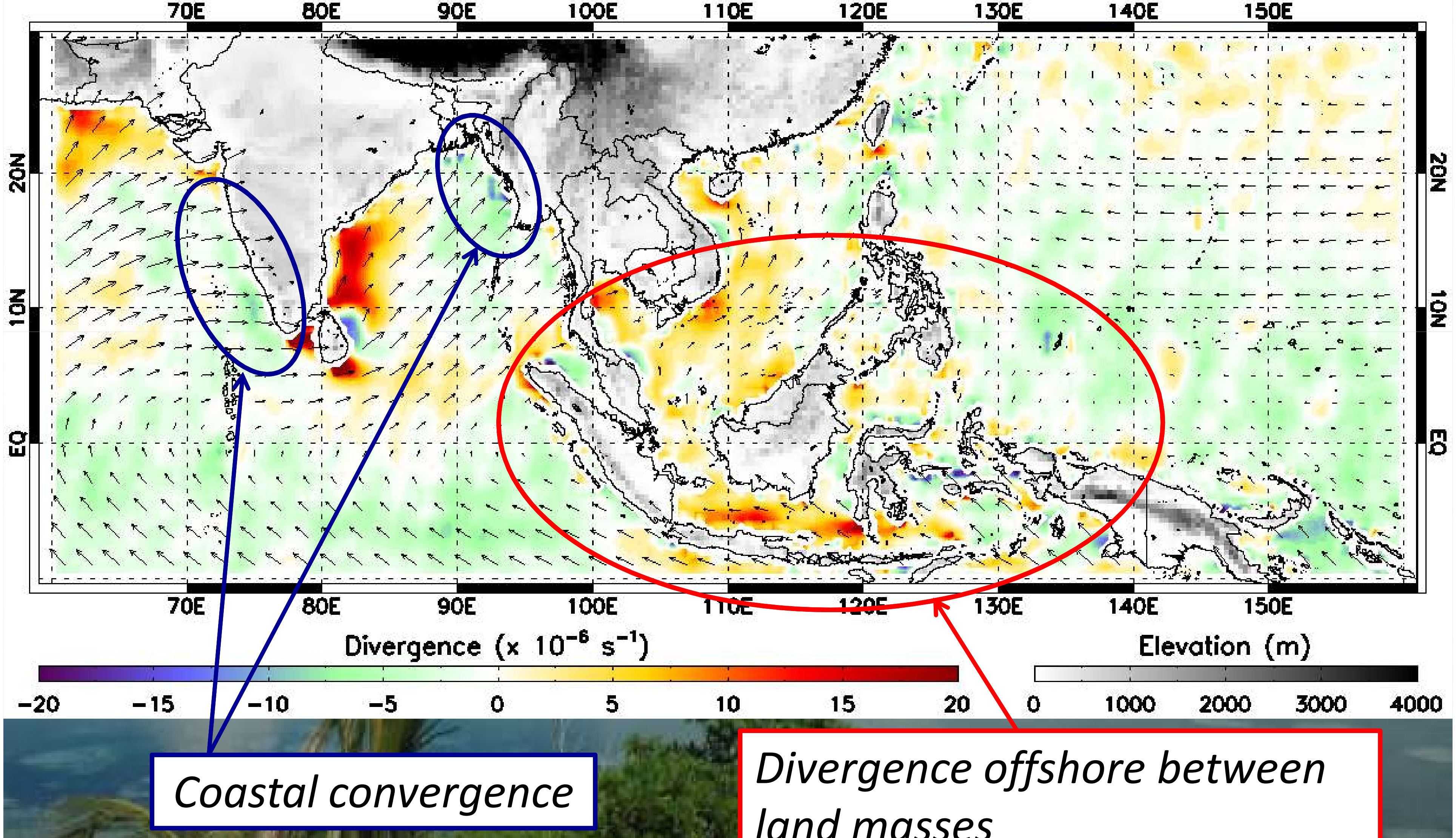




3. *Land breeze coupled with drainage flows and downdraft outflows from evening convection (Johnson and Bresch 1991; Wu et al. 2008)*
4. *Diurnally varying flow separation/blocking (e.g., Wang et al. 2000)*

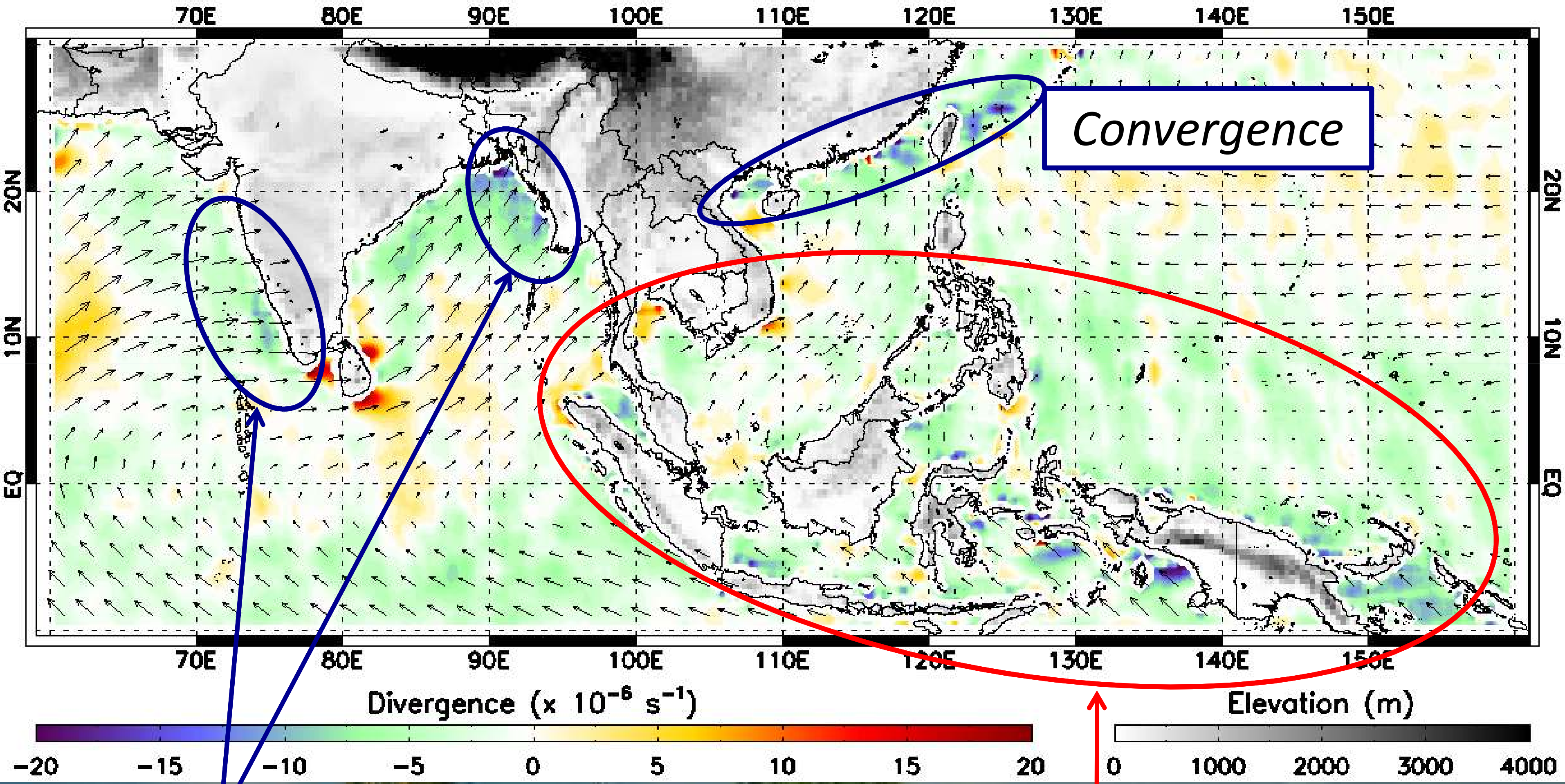
June *Evening* Surface Winds and Divergence

(2000-2007 QuikSCAT)



June *Morning* Surface Winds and Divergence

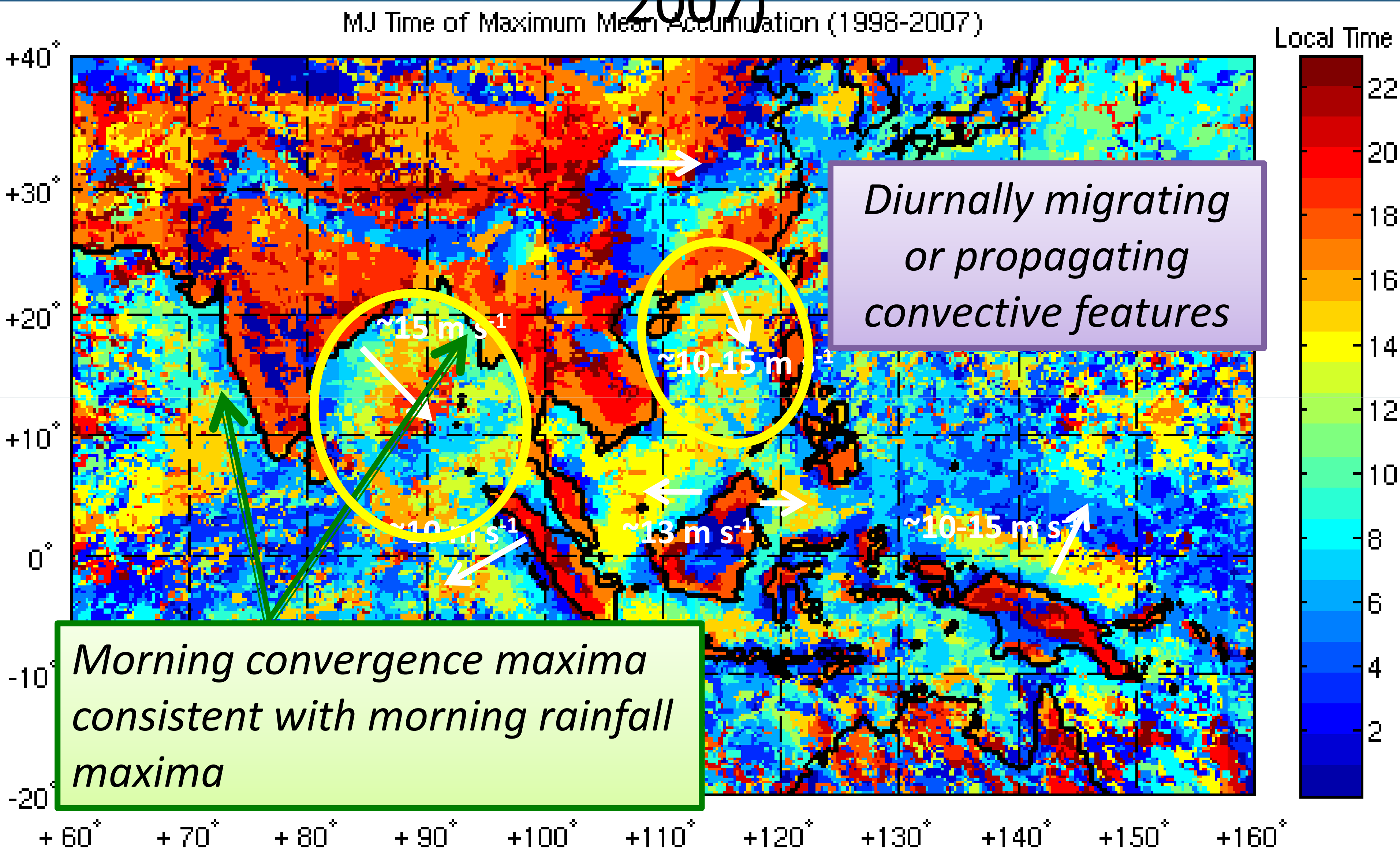
(2000-2007 QuikSCAT)

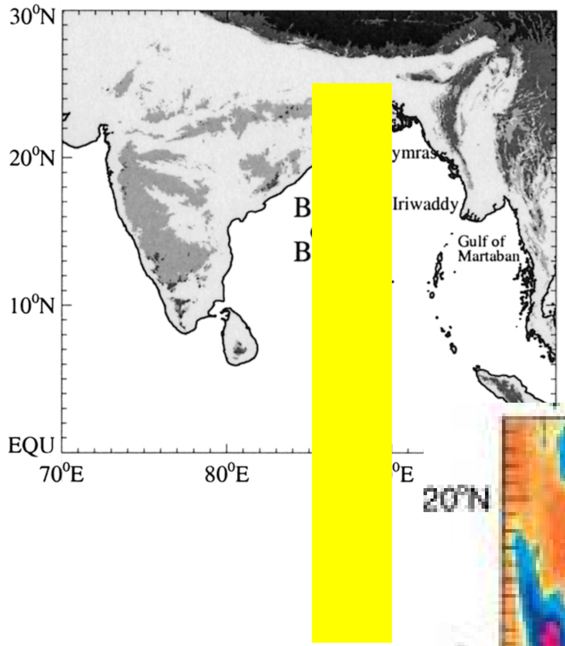


Stronger coastal convergence

Convergence offshore between land masses

Time of Maximum May-June Rainfall (1998-2007)





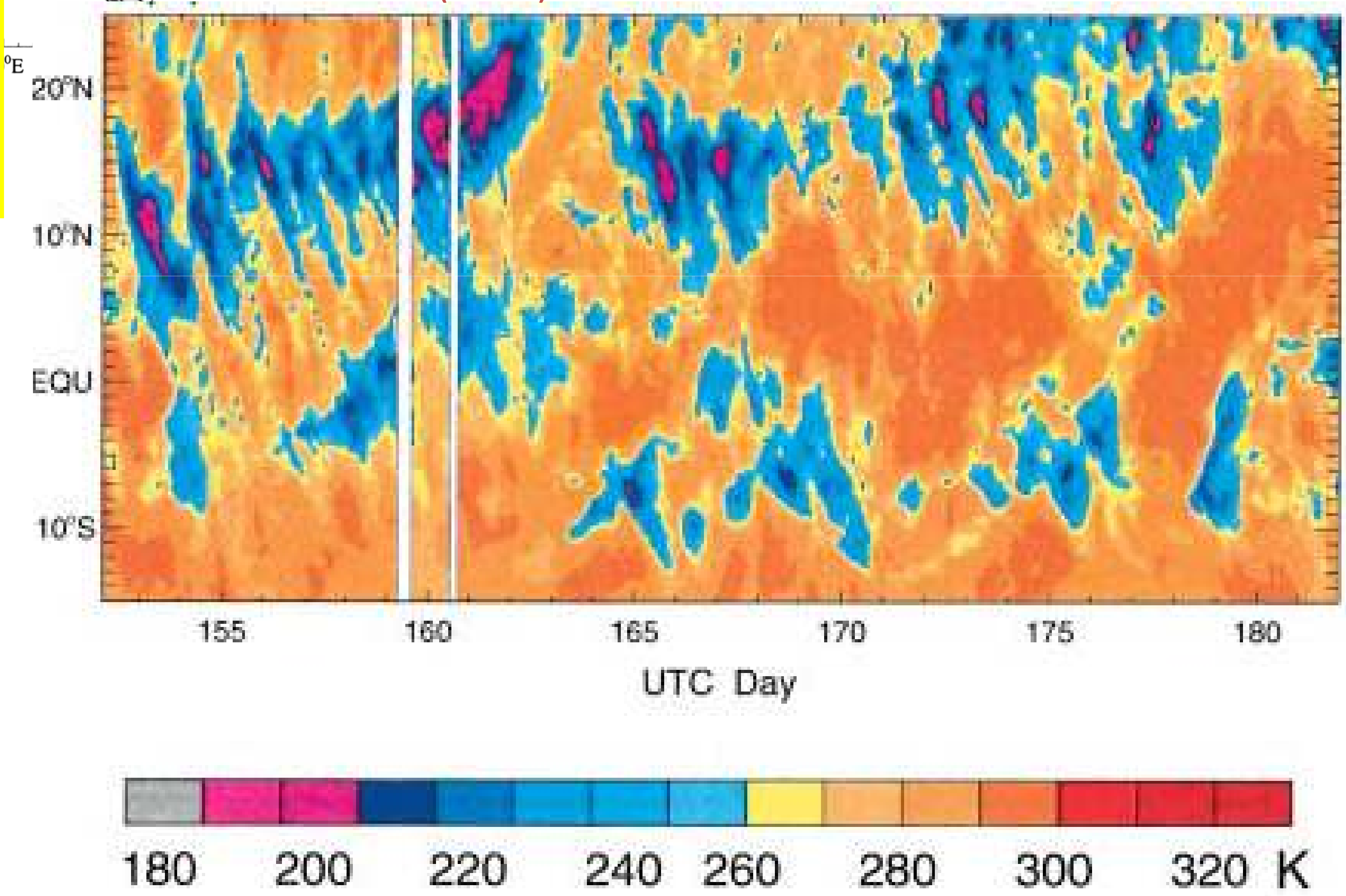
Southward-Propagating Convection over Bay of Bengal

Convective systems propagate from the coast of India over 2000 km!

Webster et al. (2002)

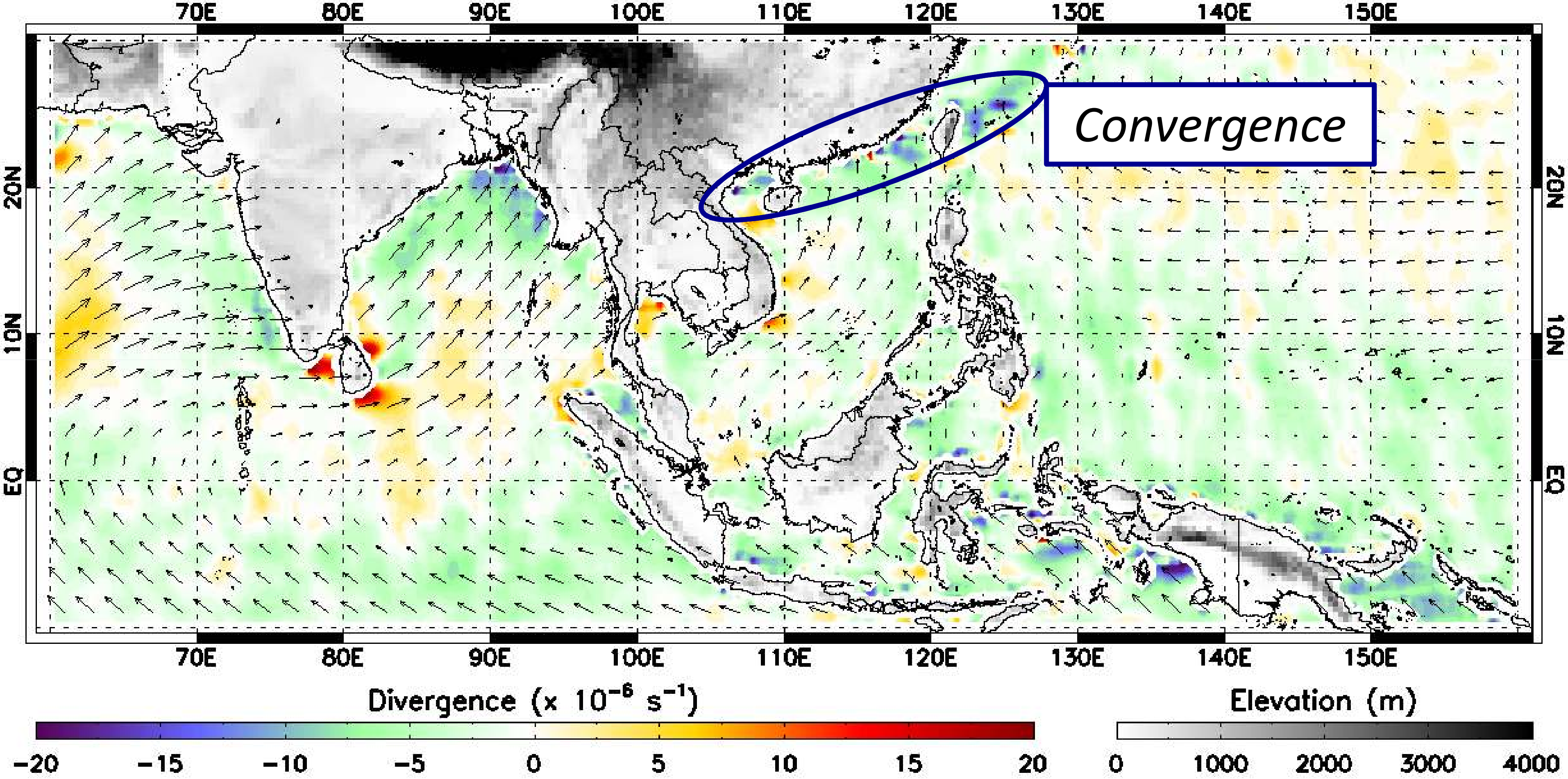
JASMINE

T_{BB} June 1999

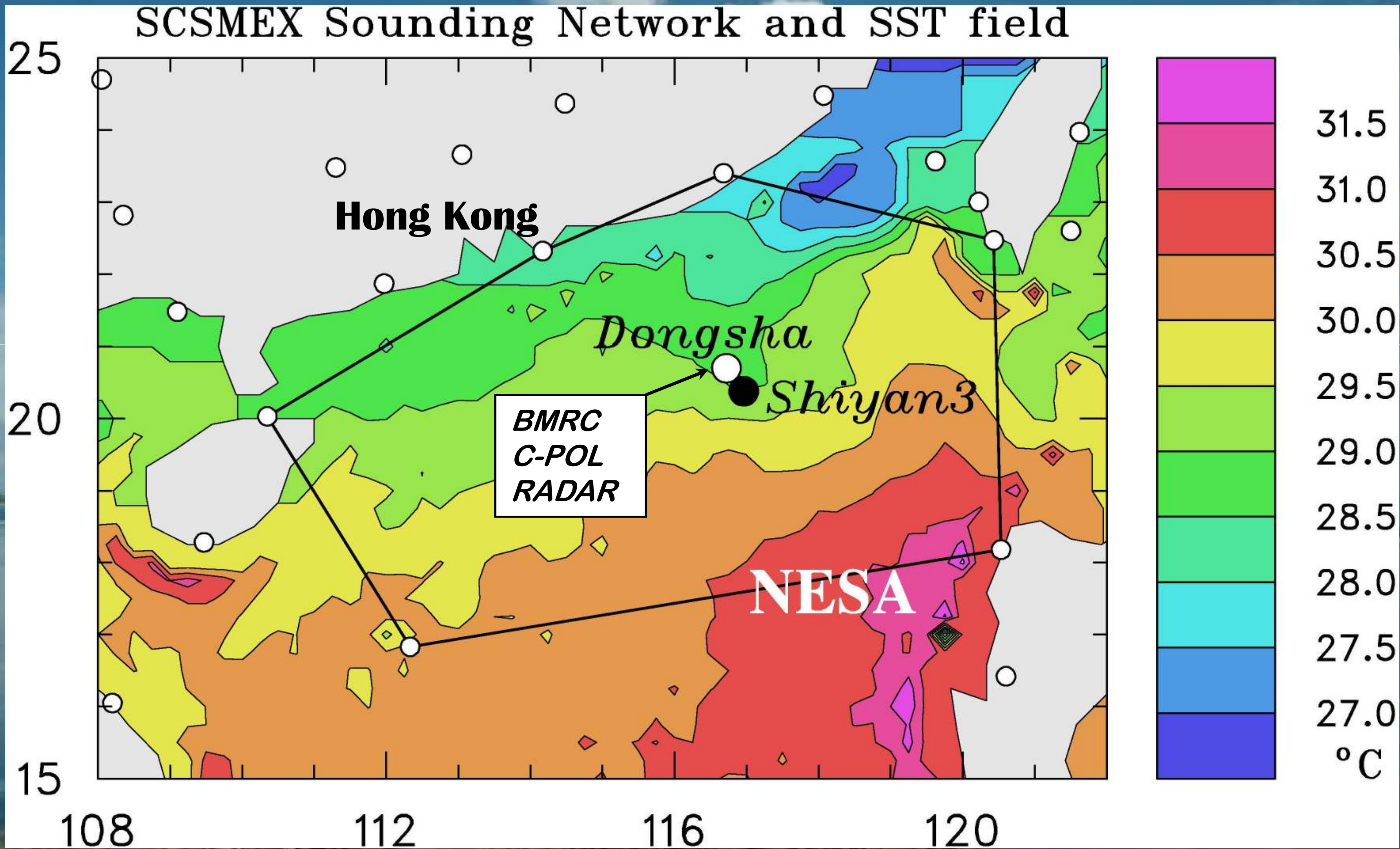


June *Morning* Surface Winds and Divergence

(2000-2007 QuikSCAT)



South China Sea Monsoon Experiment (SCSMEX) – May-June 1998



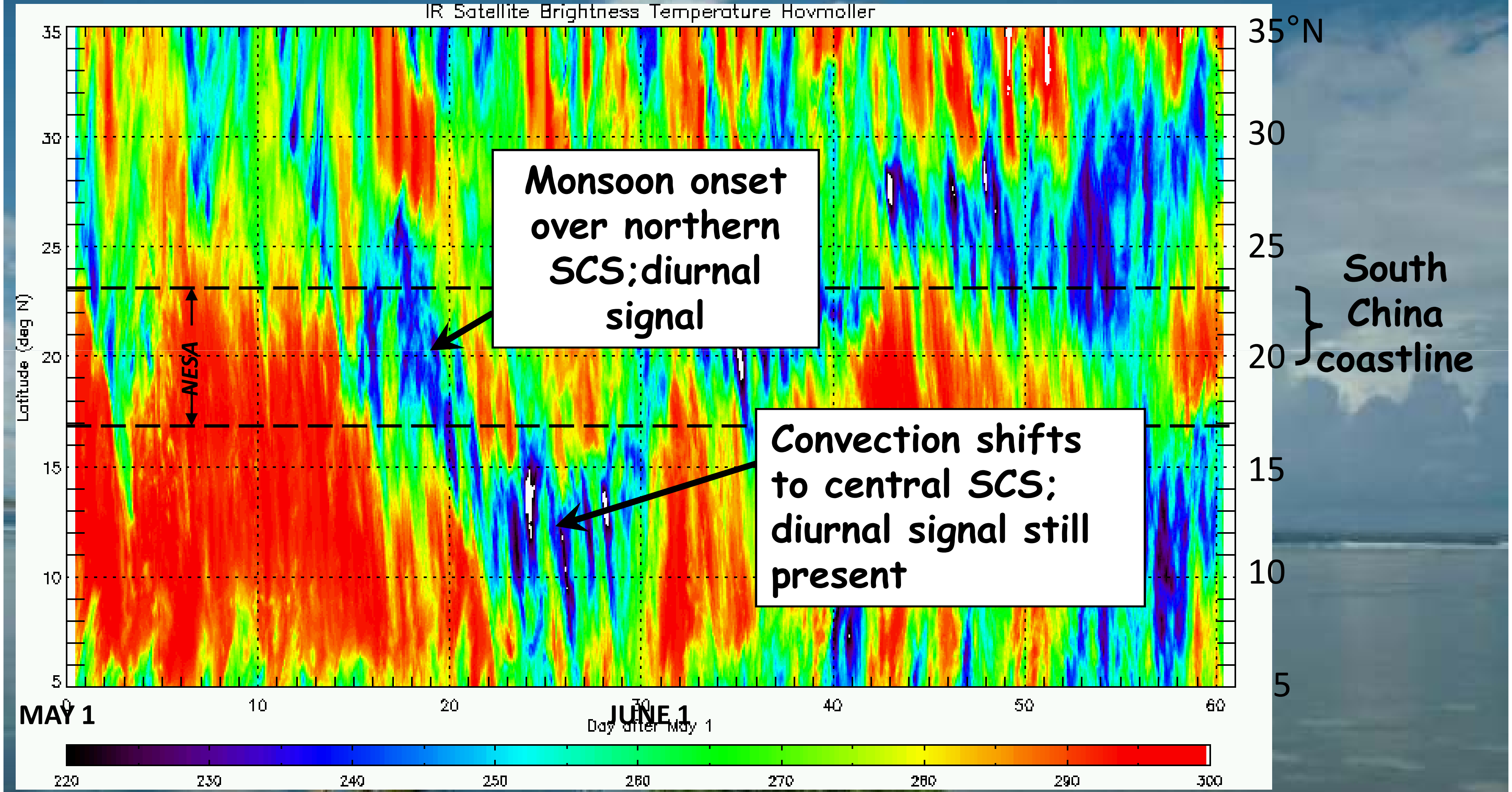

SOUTHEAST ASIA
Chengdu
Chongqing
Zigong
CHI
Guiyang
Kunming
INDIA
HENGDUAN SHAN
Mandalay
BURMA
Akyab
Hanoi
Haiphong
LAOS
Gulf of Tonkin
Vientiane
Vinh
Chiang Mai
Rangoon
Pathein
THAILAND
Nakhon Ratchasima
Hue
Mawlamyine
Dawei
Bangkok
CAMBODIA
Phnom Penh
Ho Chi Minh City
Long Xuyen
Nha Trang
CHAINE ANNAMITIQUE
Coco Channel
ANDAMAN ISLANDS (INDIA)
Andaman Sea
Gulf of Thailand
NICOBAR ISLANDS (INDIA)
Phuket
Songkhla
Great Channel
George Town
Banda Aceh
Ipoh
MALAYSIA
Medan
Strait of Malacca
Kuala Lumpur
Melaka
Pulau Simeulue
Singapore
SINGAPORE
Pulau Nias
PEGUNUNGAN BARISAN
Padang
Sumatra
Pulau Siberut
KEPULAUAN MENTAWAI
Palembang
Pulau Bangka
Billiton
Selat Karimata
Tanjungkarang Telukbetung
Jakarta
Selat Sunda
Bandung
Semarang
Java
Java Sea
Madura
Surabaya
Bali
Lombok
Denpasar
Selat Lombok
Sumbawa
Sumba
Flores
Flores Sea
Christmas Island (AUSTRALIA)
Cocos (Keeling) Islands (AUSTRALIA)
Indian Ocean
Scale 1:32,000,000 at 5°N
Mercator Projection
500 Kilometers
500 Miles
Boundary representation is not necessarily authoritative.
Names in Vietnam are shown without diacritical marks.
KEPULAUAN NATUNA
BRUNEI
MALAYSIA
Kuching
Borneo
Pontianak
Samarinda
Makassar Strait
Banjarmasin
INDONESIA
Makassar
Sulawesi (Celebes)
Palu
Kendari
Shanghai
East China Sea
JAPAN
Okinawa
Naha
RYUKYU ISLANDS (JAPAN)
DAITO-SHOTO (JAPAN)
NAMPO SHOTO (JAPAN)
BONIN ISLANDS
VOLCANO ISLANDS
Taipei
Tropic of Cancer
Taiwan
Okino-tori-shima (JAPAN)
Luzon Strait
BABUYAN ISLANDS
Philippine Sea
Luzon
Manila
Samar
Panay
Iloilo
Cebu
Bacolod
Negros
Cagayan de Oro
Mindanao
Davao
FED. STATES OF MICRONESIA
Koror
PALAU
Celebes Sea
North Pacific Ocean
Manado
Halmahera
Molucca Sea
Equator
Sorong
Ceram
Buru
Ambon
Jayapura
PEGUNUNGAN MAOKE
New Guinea
PAPUA NEW GUINEA
Banda Sea
KEPULAUAN ARU
Arafura Sea
Merauke
Dili
EAST TIMOR
Kupang
Timor
Timor Sea
Ashmore and Cartier Islands (AUSTRALIA)
Darwin
Gulf of Carpentaria
AUSTRALIA
GREAT SANDY DESERT
Port Hedland
Karratha
Mount Isa
802914AI (R02106) 6-02

20°N

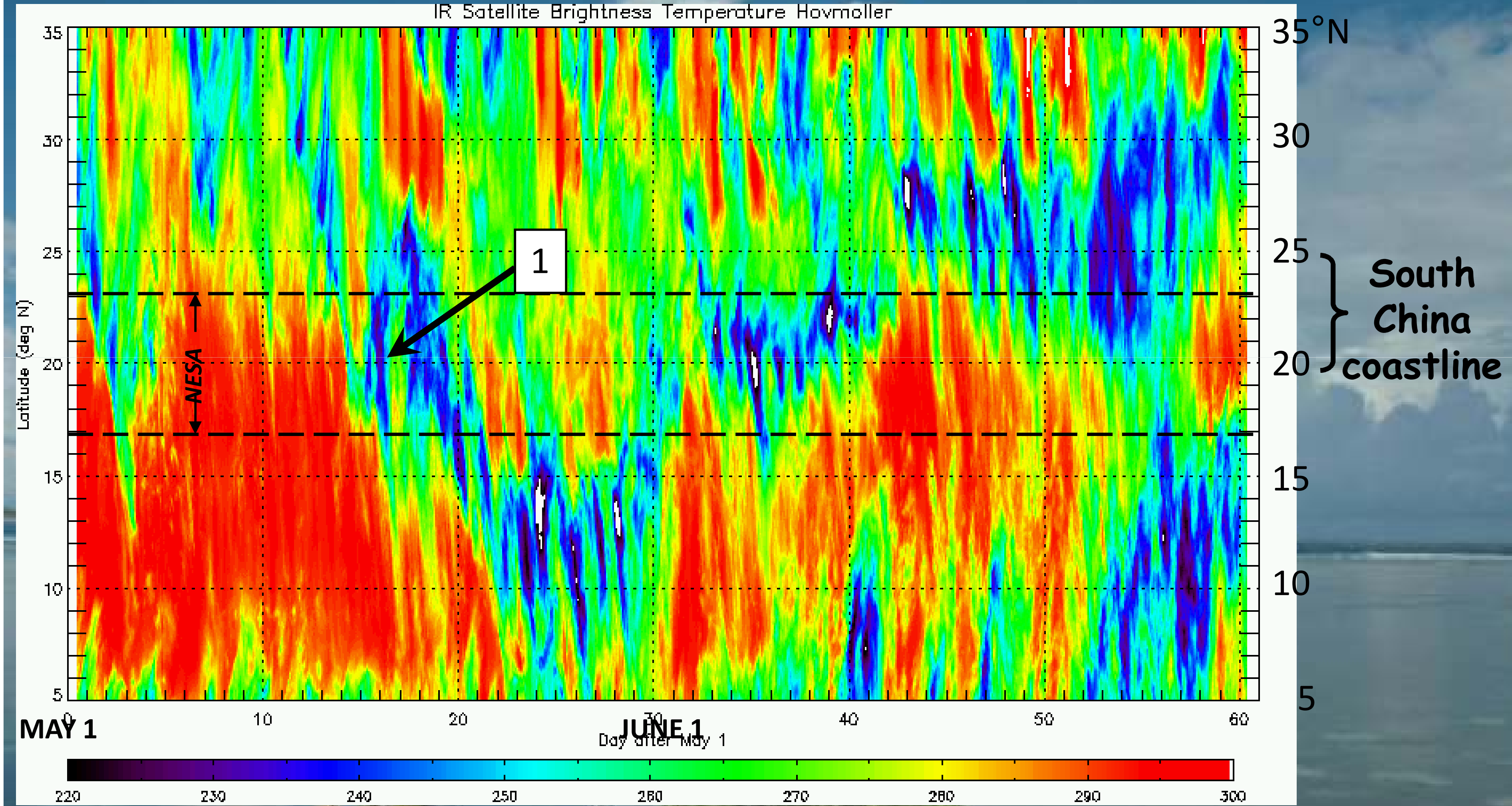
10°

EQ

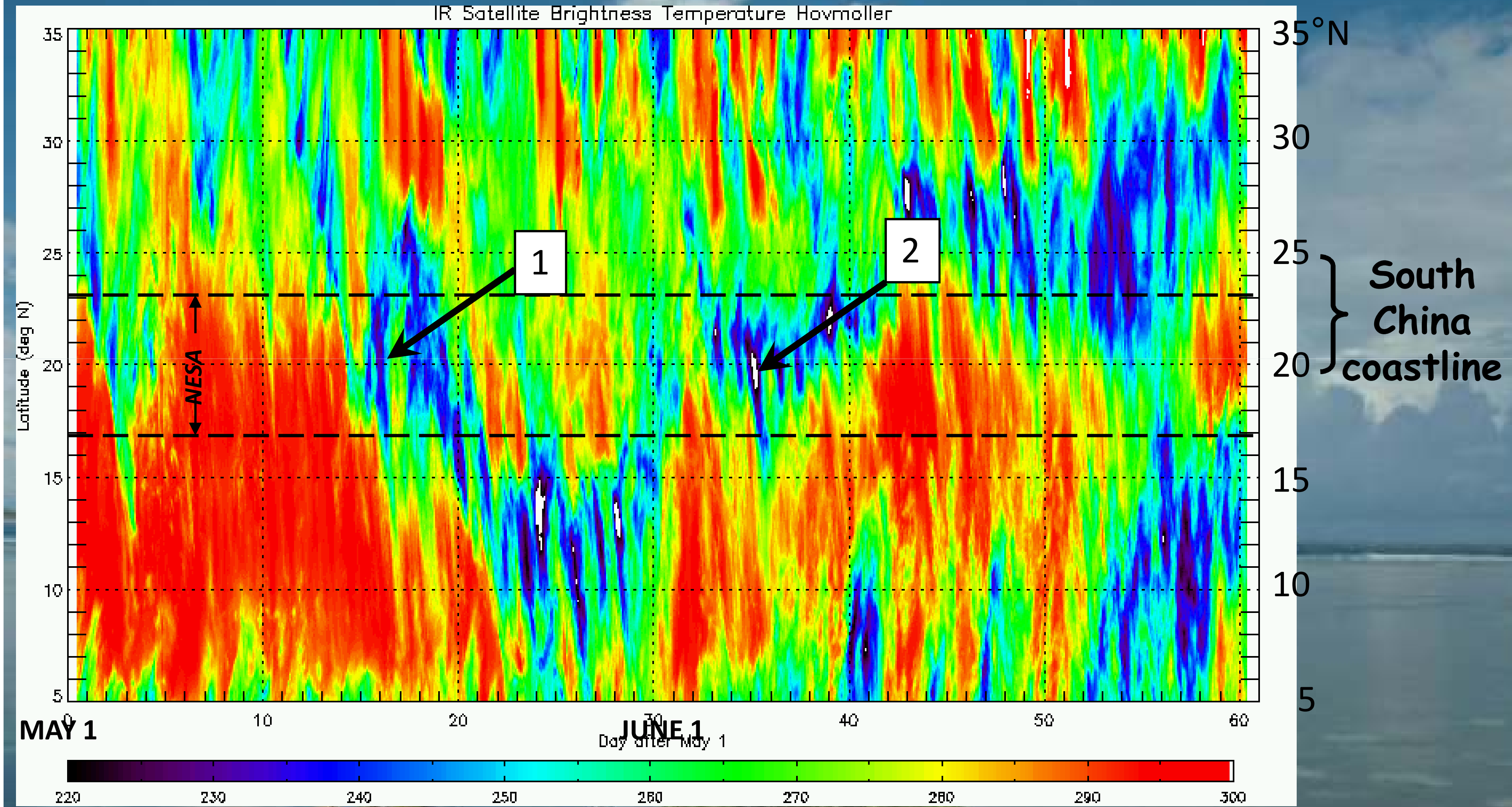
GMS Brightness Temperatures
110-120°E (South China Sea)
1 May – 30 June 1998

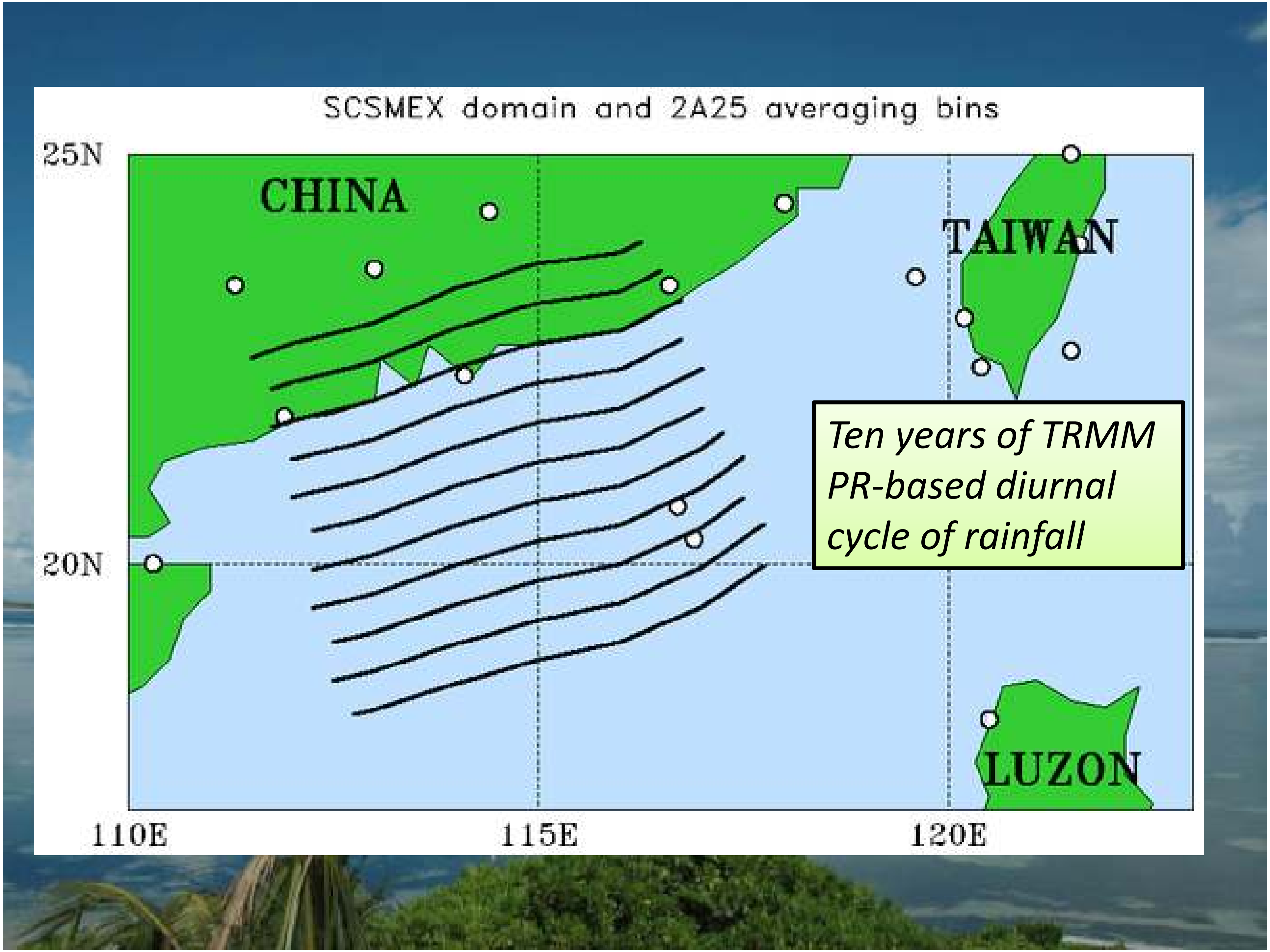


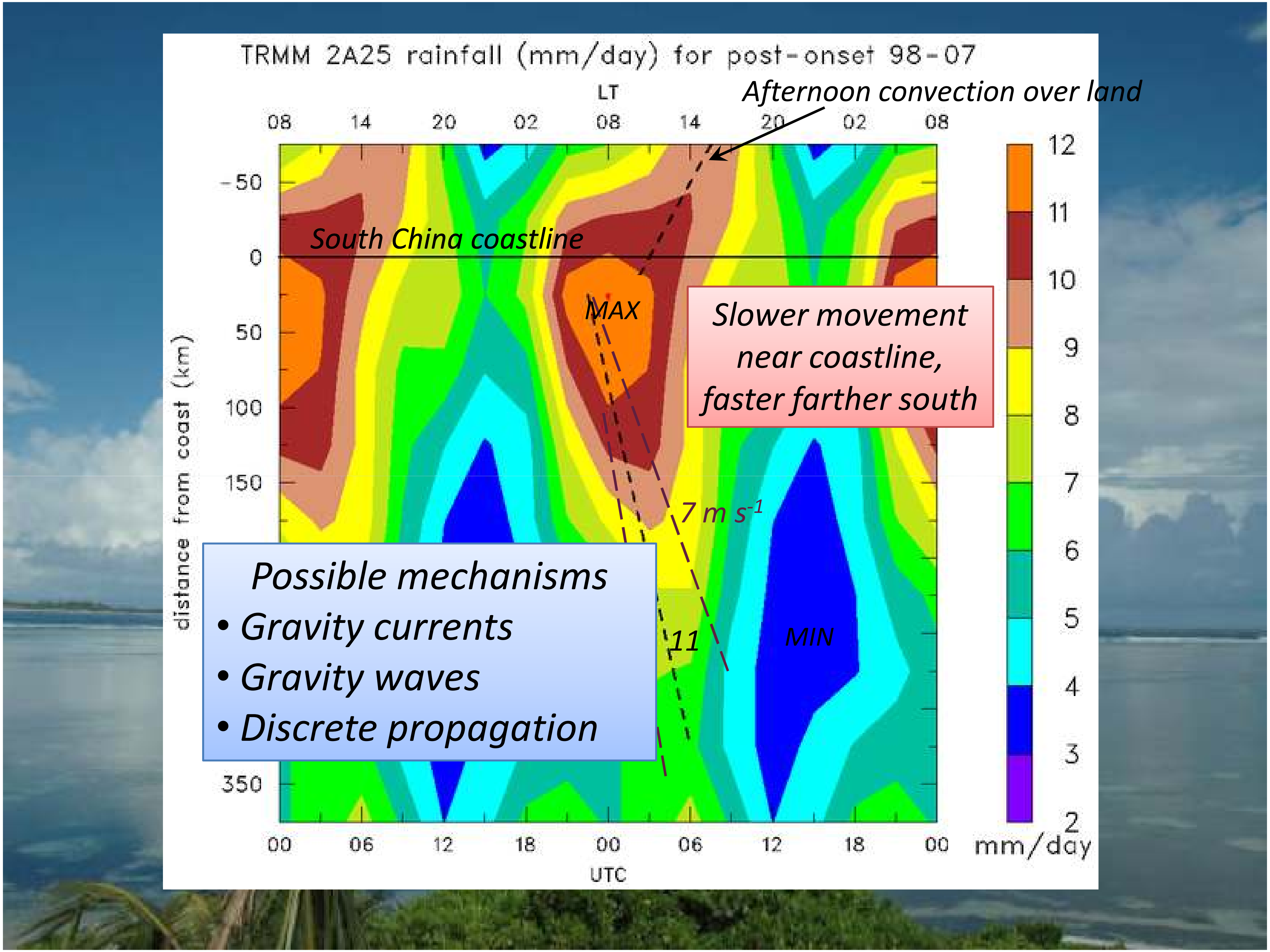
GMS Brightness Temperatures
110-120°E (South China Sea)
1 May – 30 June 1998



GMS Brightness Temperatures
110-120°E (South China Sea)
1 May – 30 June 1998

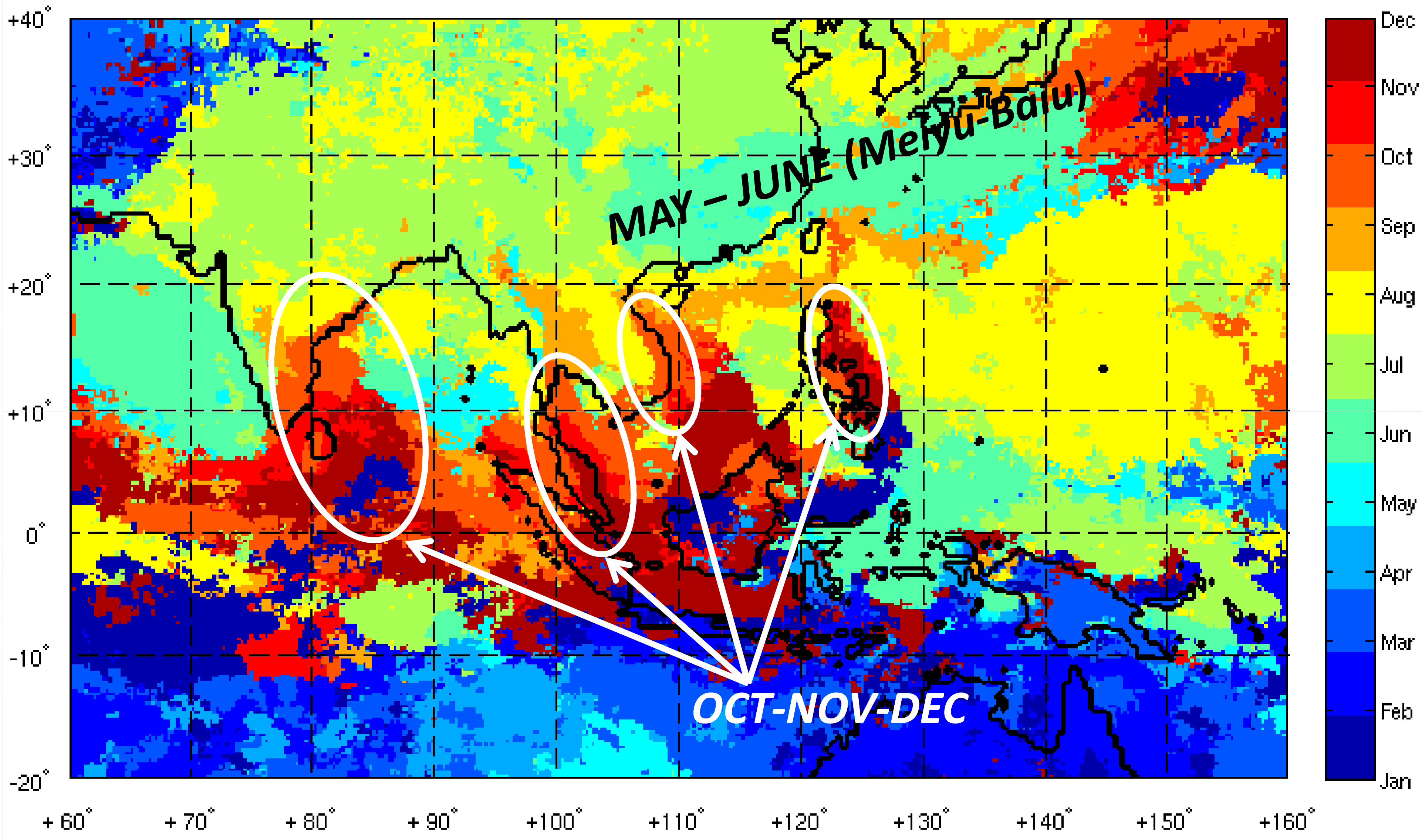


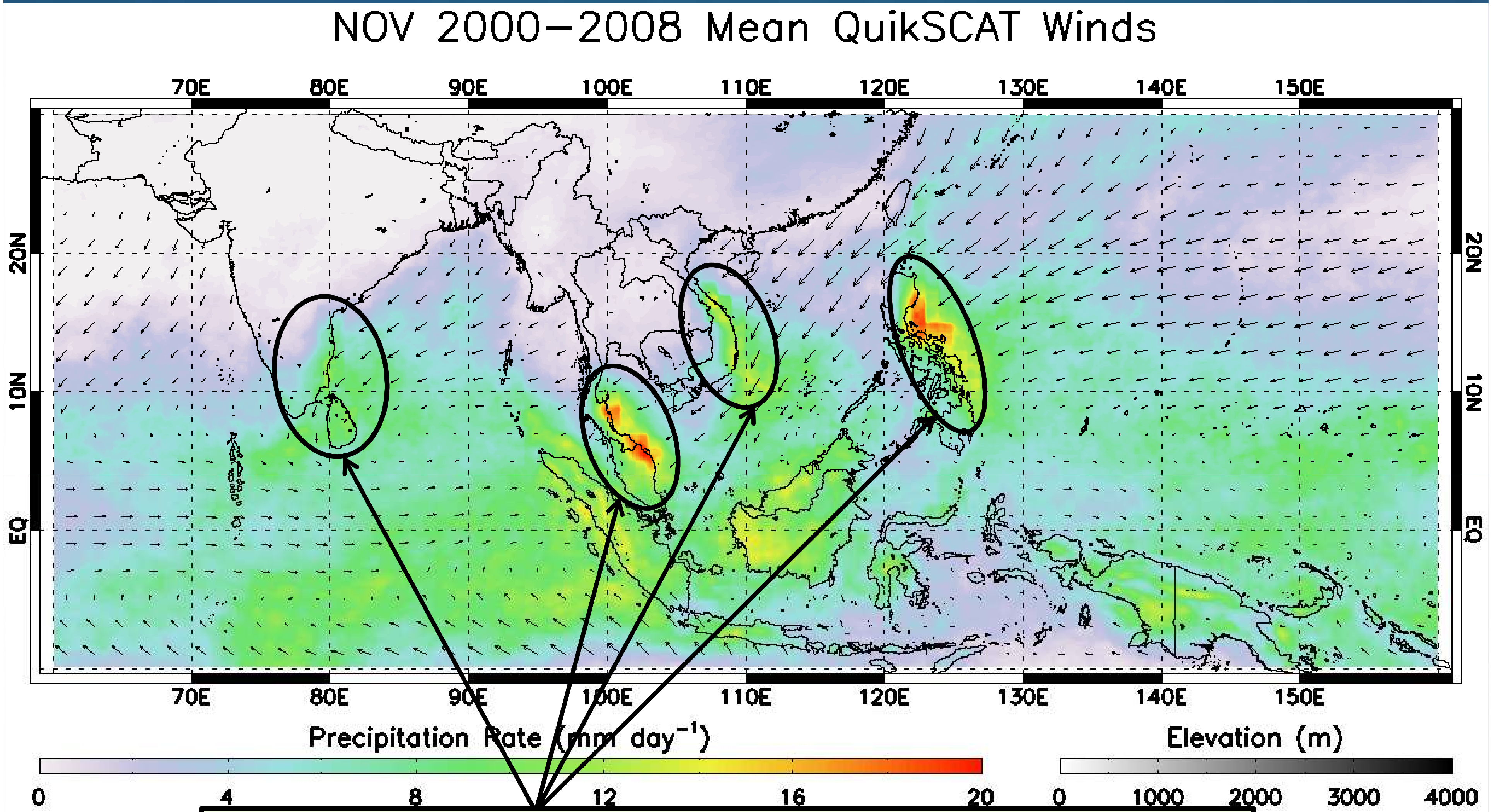

SCSMEX domain and 2A25 averaging bins
25N
20N
110E
115E
120E
CHINA
TAIWAN
LUZON
Ten years of TRMM PR-based diurnal cycle of rainfall



TRMM 2A25 rainfall (mm/day) for post-onset 98-07
LT
08 14 20 02 08 14 20 02 08
Afternoon convection over land
-50
0
50
100
150
350
distance from coast (km)
South China coastline
MAX
Slower movement near coastline, faster farther south
7 m s-1
11
MIN
Possible mechanisms
• Gravity currents
• Gravity waves
• Discrete propagation
00 06 12 18 00 06 12 18 00
UTC
12 11 10 9 8 7 6 5 4 3 2
mm/day

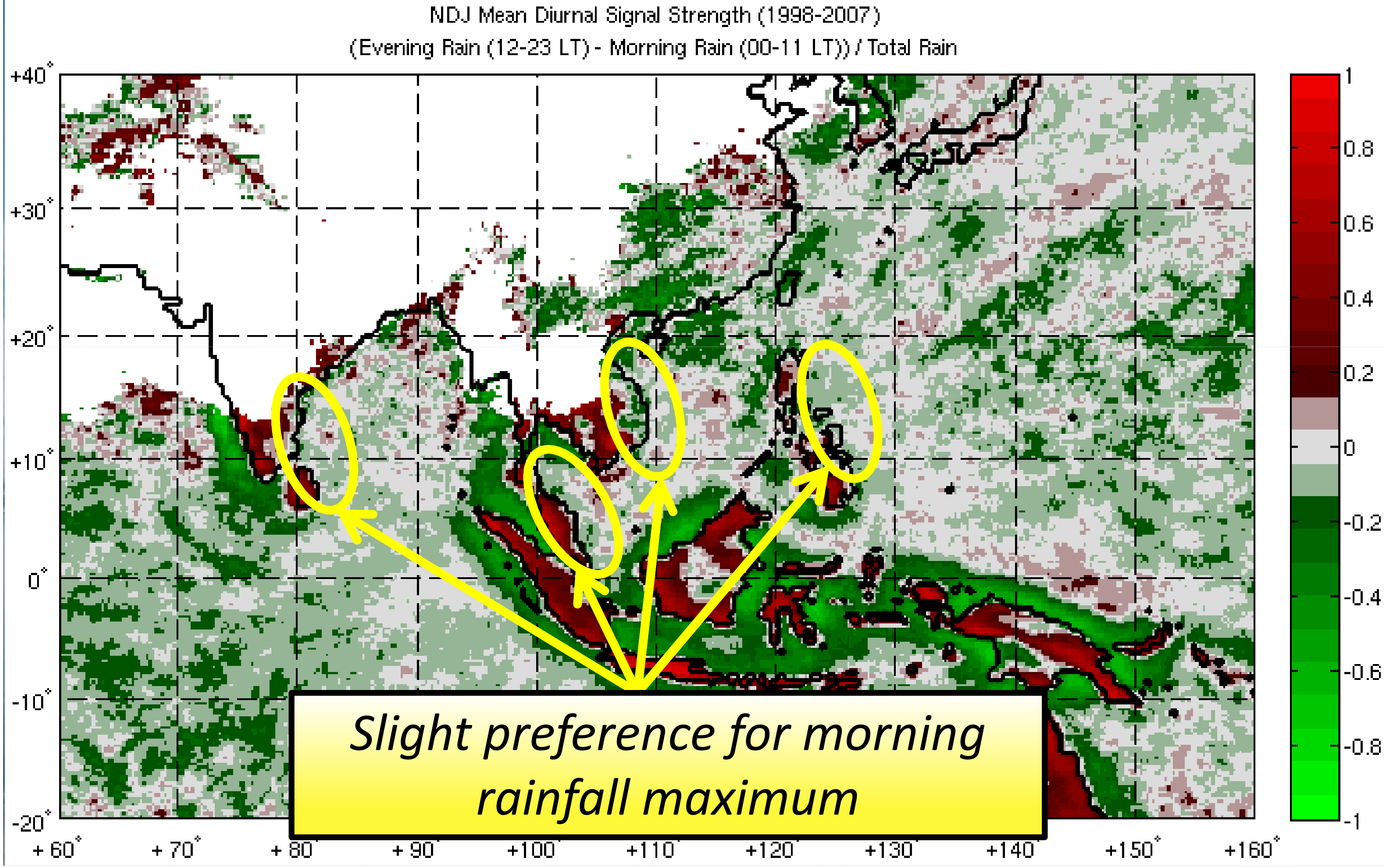
TRMM 3B42 MONTH OF MAXIMUM RAINFALL (1998-2007)

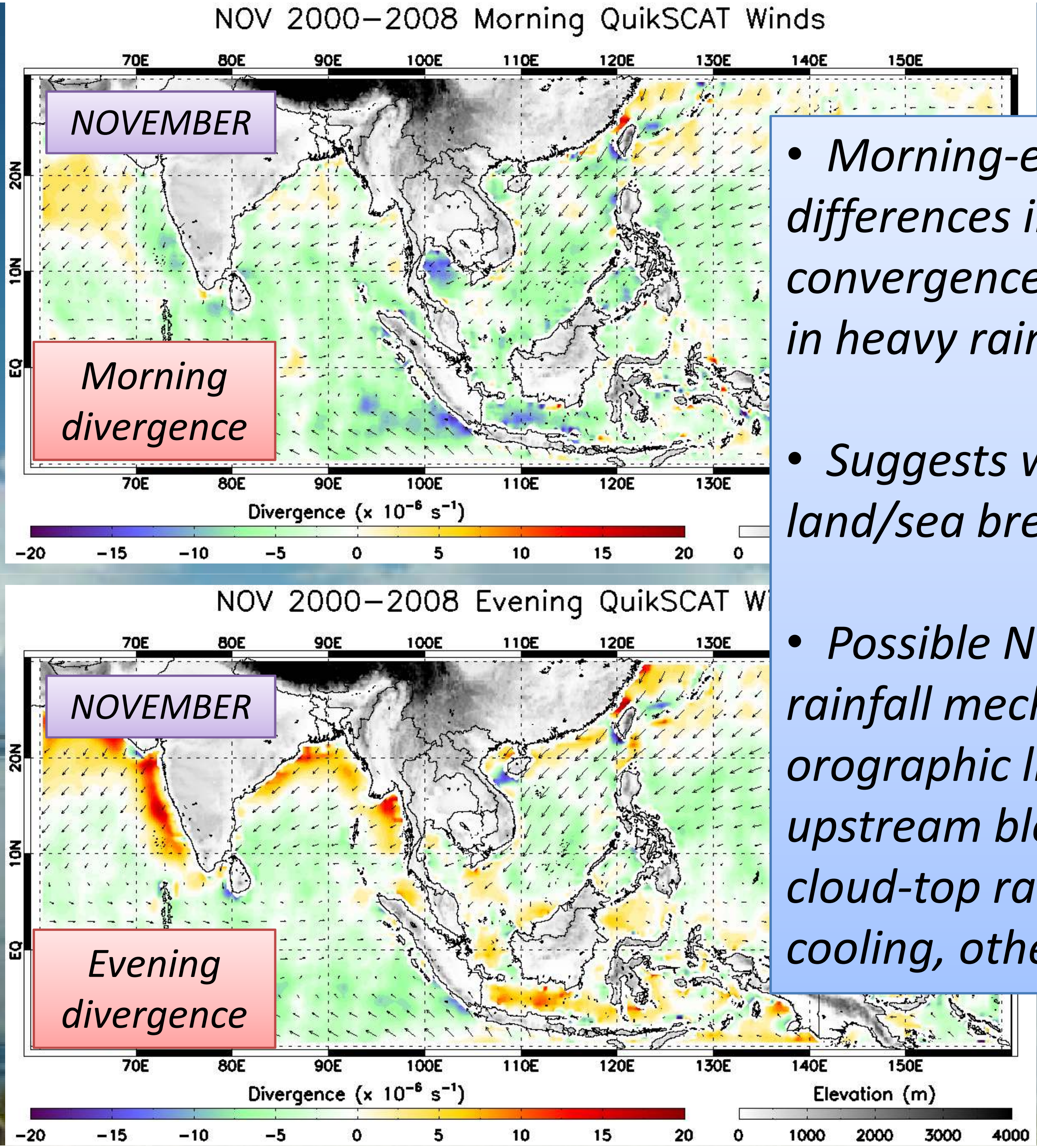




HEAVY RAINFALL ASSOCIATED WITH OROGRAPHIC LIFTING AND/OR COASTAL CONVERGENCE IN NORTHEAST MONSOON FLOW

Normalized Amplitude, Mean Diurnal Cycle of Nov-Dec-Jan Rainfall (1998-2007)





- *Morning-evening differences in coastal convergence are small in heavy rain areas*
- *Suggests weak land/sea breeze effects*
- *Possible NE coastal rainfall mechanisms: orographic lift, upstream blocking, cloud-top radiative cooling, others?*

Summary and Conclusions

- Heavy rain areas in tropics and monsoon regions exhibit prominent diurnal cycle
- Afternoon/evening rain over land, nocturnal rain over ocean predominate, but important exceptions (e.g., morning rainfall at foot of Himalayas, afternoon rainfall over tropical ocean in light winds)
- Downstream propagation of convection from major mountain barriers

Summary and Conclusions

- Large rainfall maxima upstream of Western Ghats and Myanmar, peaking at nighttime/morning hours
- Seaward migration/propagation of convection prevalent throughout Asian summer monsoon; mechanisms unresolved – could involve gravity currents, waves, discrete propagation
- Weak diurnal cycle of rainfall in coastal, heavy-rain areas during boreal winter monsoon