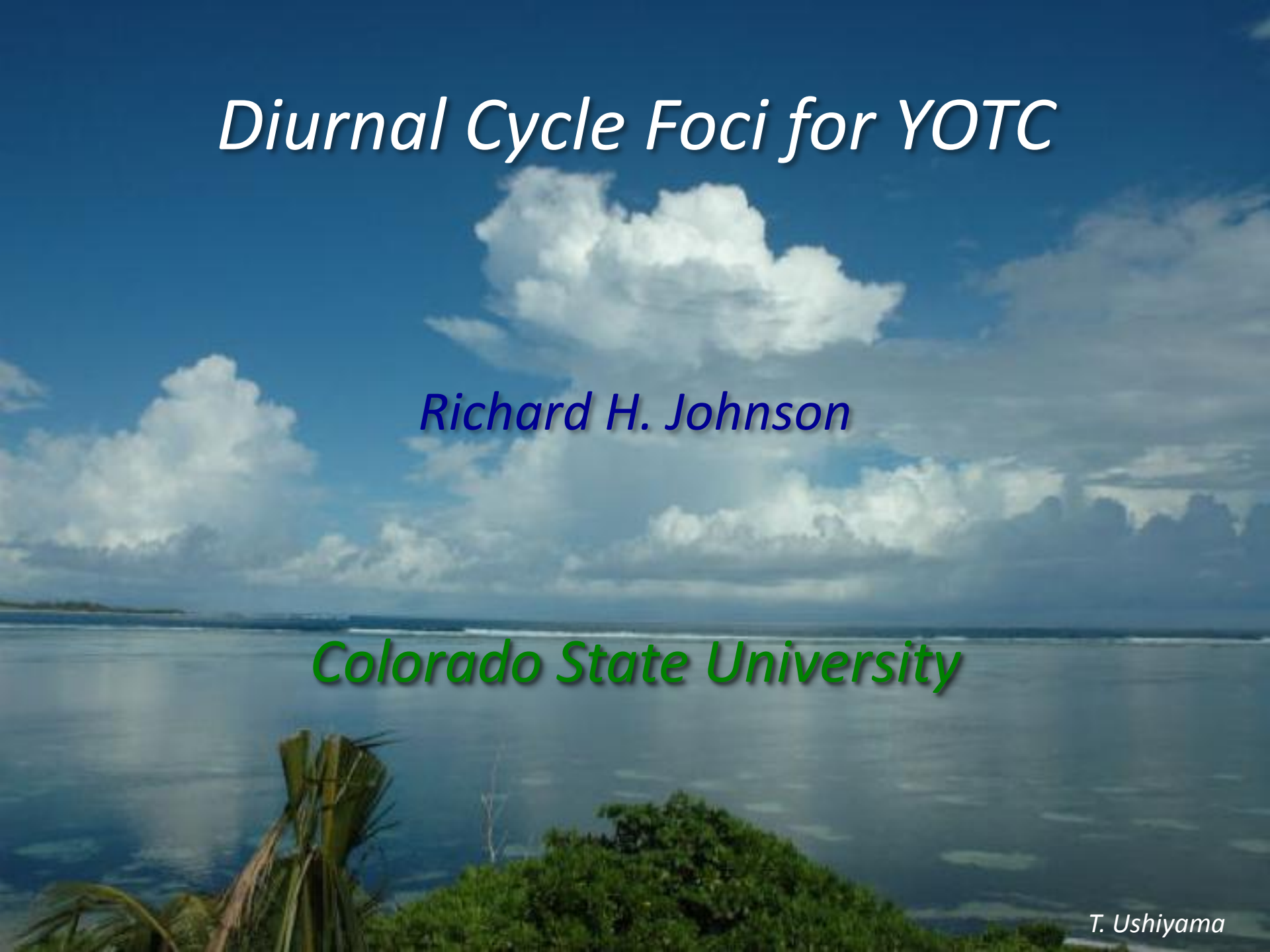
Diurnal Cycle Foci for YOTC

Richard H. Johnson

Colorado State University



T. Ushiyama

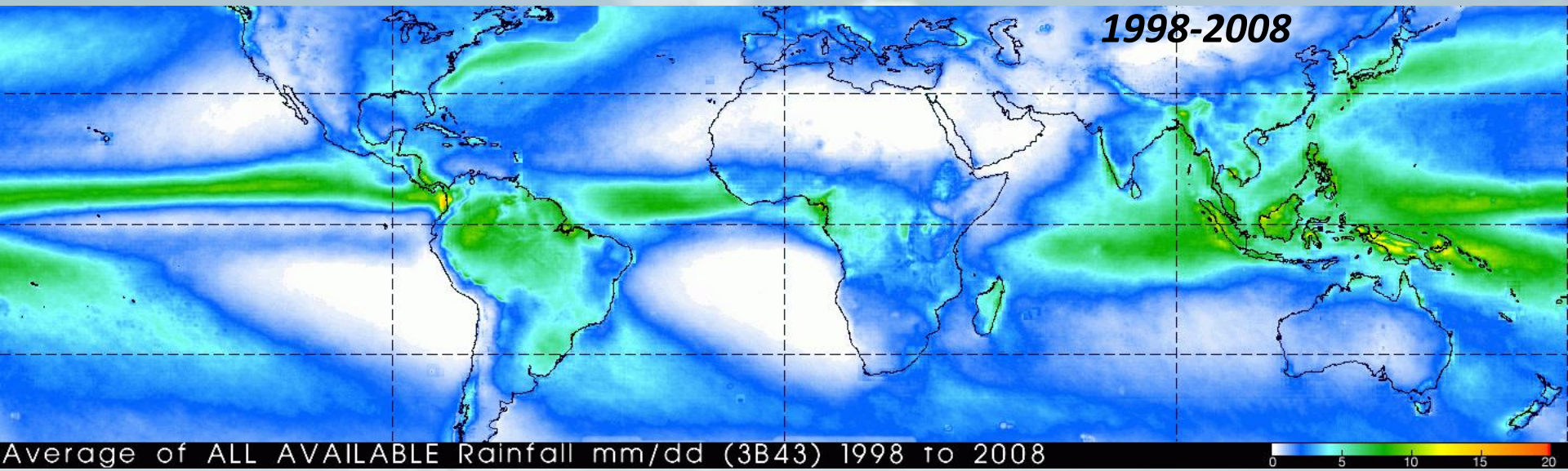
Diurnal Cycle in the Tropics

- 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)
- Evidence is emerging that the diurnal cycle is important for equatorial waves and the MJO

Potential Diurnal Cycle Foci for YOTC

- Diurnal cycle over open ocean
- Impact of diurnal cycle on tropical waves (convectively coupled waves)
- Migrating, propagating diurnal signals over ocean near continents
- Diurnal cycle over maritime continent; modulation by the MJO, ENSO, IOD, other
- Diurnal cycle of convection over West Africa, coupling with AEWs
- Role of diurnal cycle in extreme rainfall along coastlines in monsoon regions
- Diurnal cycle and development of 2009 El Niño

TRMM 3B43* 11-year Mean Rainfall



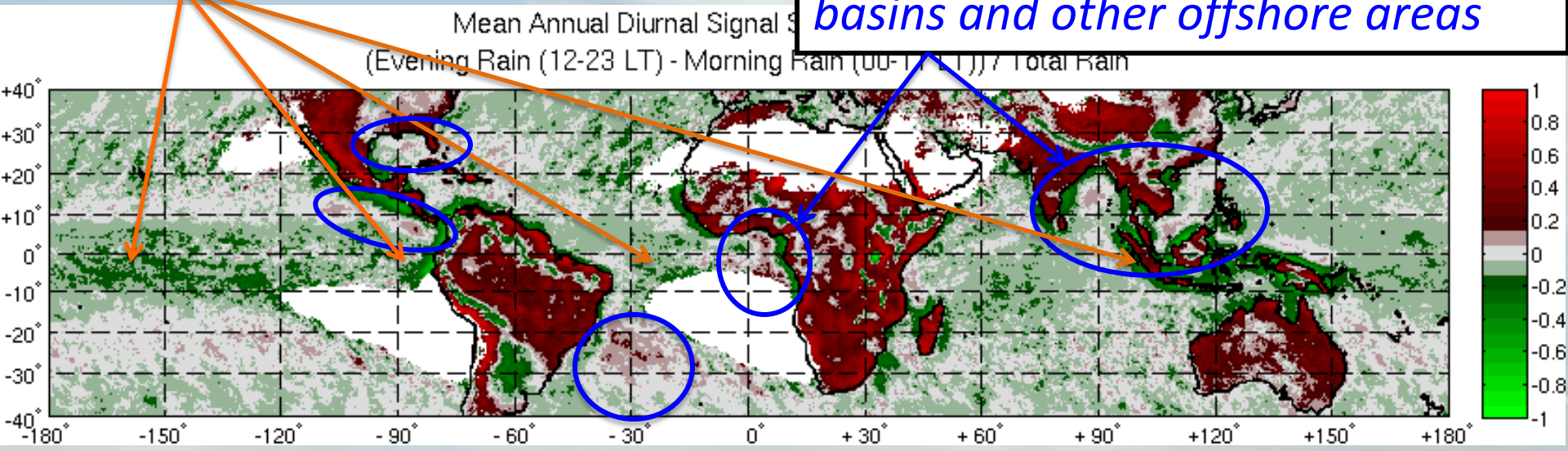
- *Much of world's heaviest rainfall in tropics and monsoon regions occurs in ITCZs/SPCZ, over maritime continent, Amazon, and along coastlines ⇒ diurnal cycle is important*

* 3B42 (Geostationary IR precipitation estimates adjusted by optimal combination of TRMM, SSMI, AMSR, AMSU, and other microwave measurements scaled to match monthly rain gauge observations) merged with GPCC rain gauge analysis

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]

÷

[Annual Mean Rainfall]

(excluding areas with < 100 mm rainfall per year)

Diurnal Cycle over Open Ocean

- Nocturnal maximum predominates: proposed mechanisms
  - Cloud-top shortwave absorption/longwave cooling
  - Horizontal gradients in longwave cooling from clear to cloudy regions
  - Day-night variation in lower-tropospheric precipitable water
  - SST diurnal cycle, growth of MCSs
  - Semidiurnal pressure wave

Diurnal Cycle over Open Ocean

- *Important exception to nocturnal maximum: light-wind conditions over tropical oceans where shallow diurnal warm layer develops in the upper ocean*
- *Examples: western Pacific during the light-wind phase of MJO, as seen during 1992-93 TOGA COARE; Indian Ocean during MISMO 2006 and VASCO-CIRENE 2007*
- *Will discuss in context of MJO…*

Impact of Diurnal Cycle on Equatorial Waves

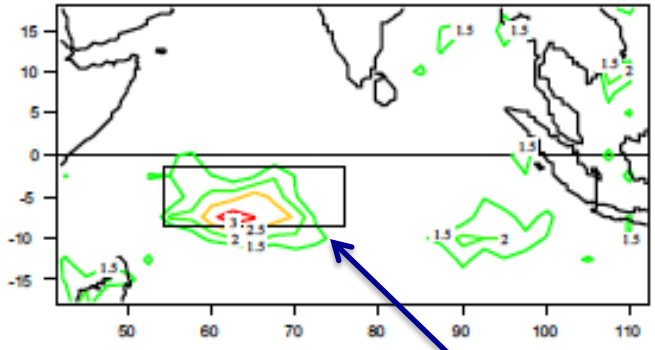
- MJO (inactive and active phases)
- Kelvin waves
- Westward inertio-gravity waves
- Other?

Physical origin of the intraseasonal SST variability

(Duvel et al. 2008)

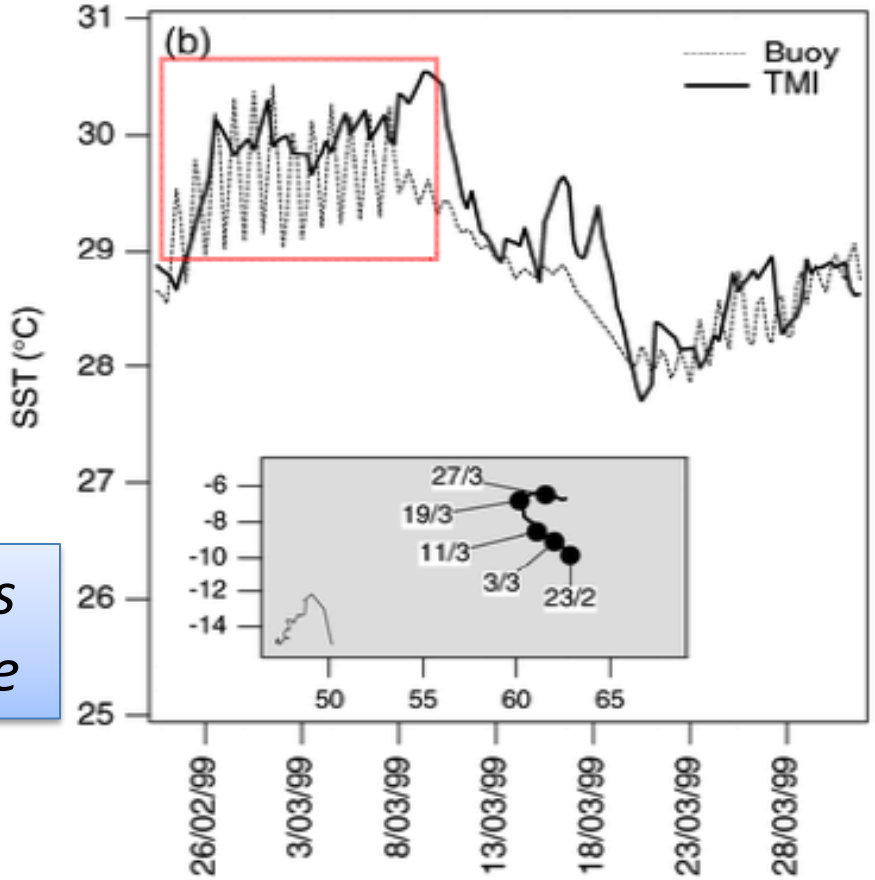
- Diurnal Warm Layer formation

SST PERTURBATION RELATED TO ISO

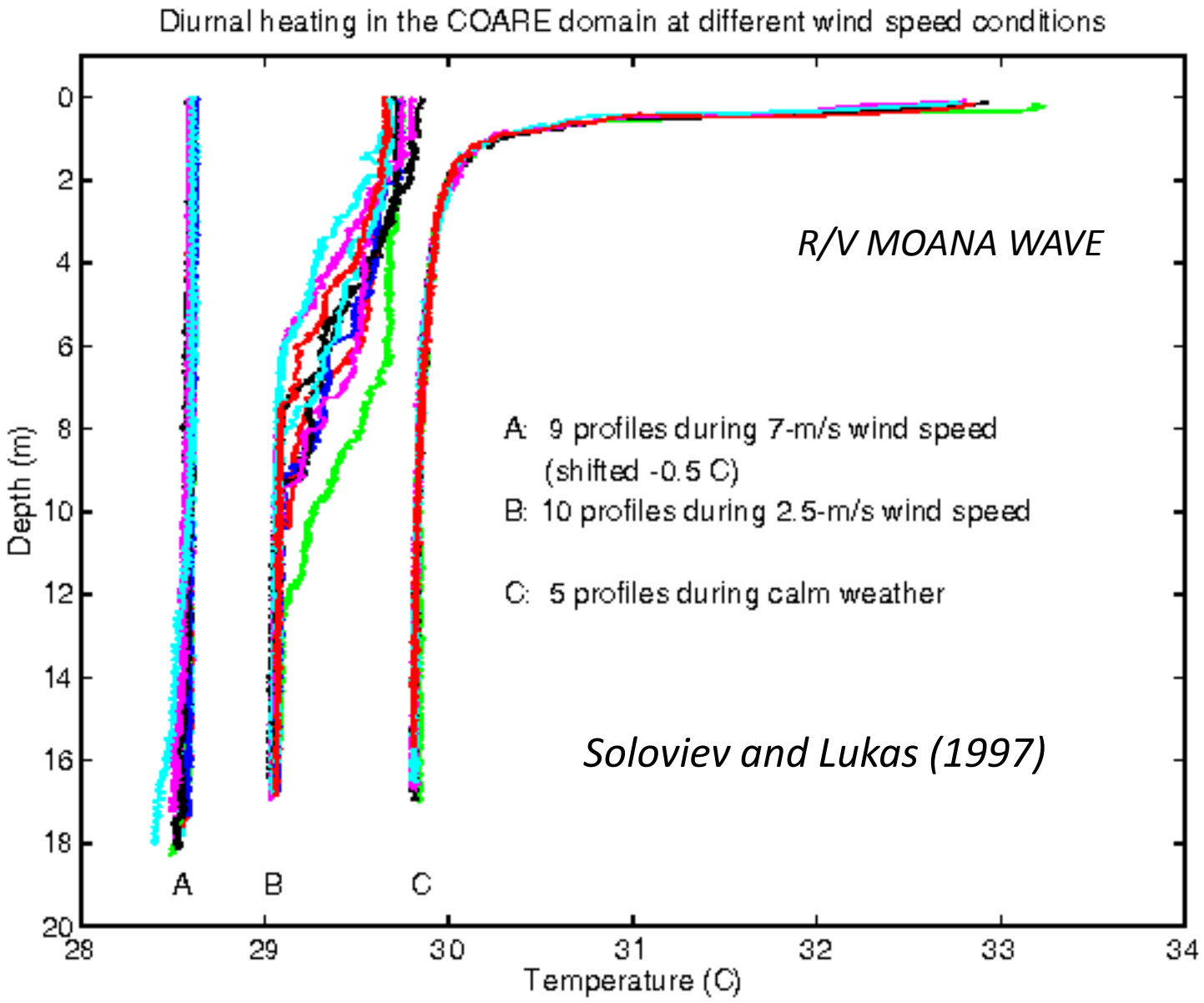


Duvel et al. (2004)

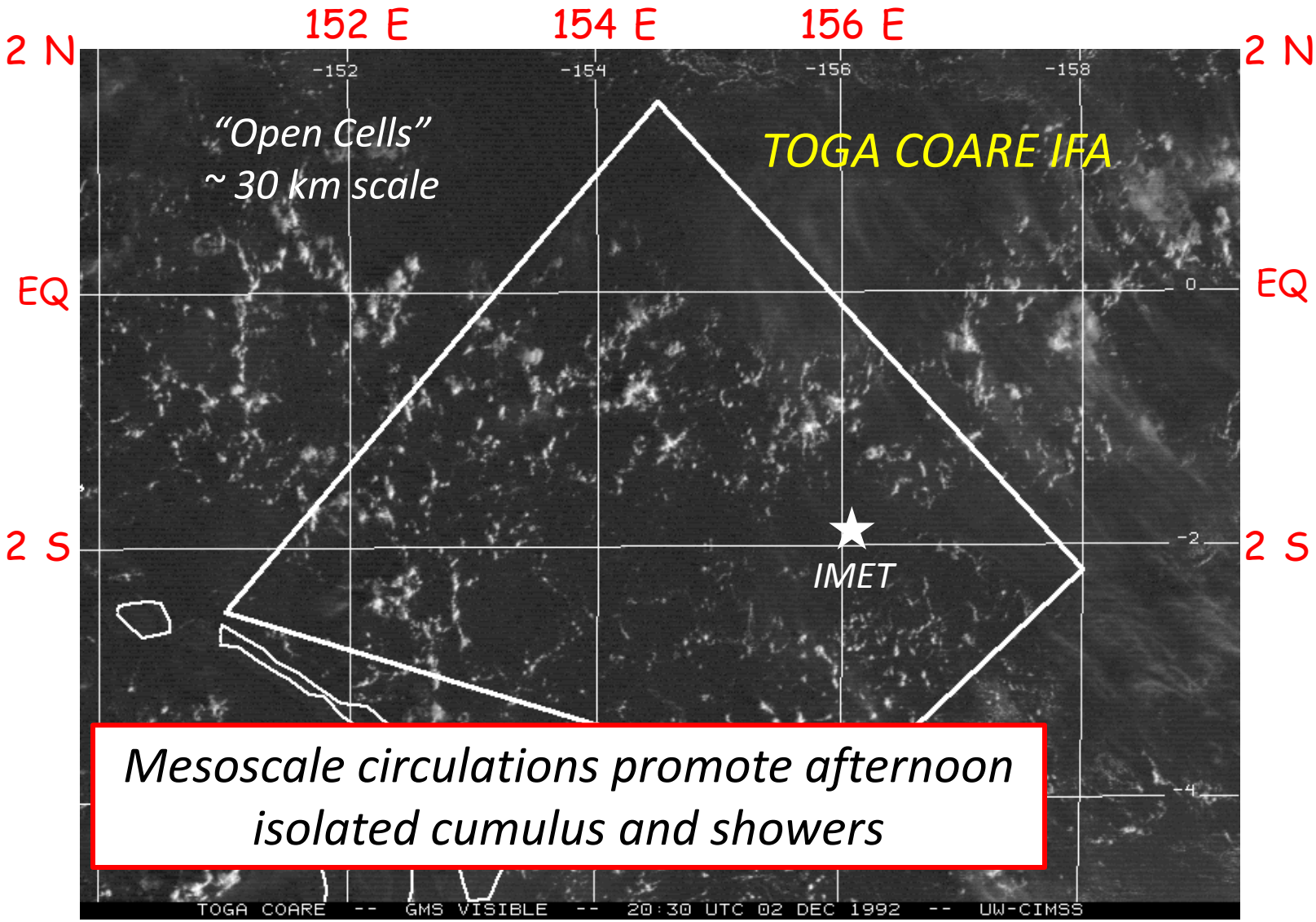
Seychelles-Chagos Thermocline Ridge



Diurnal Warm Layer

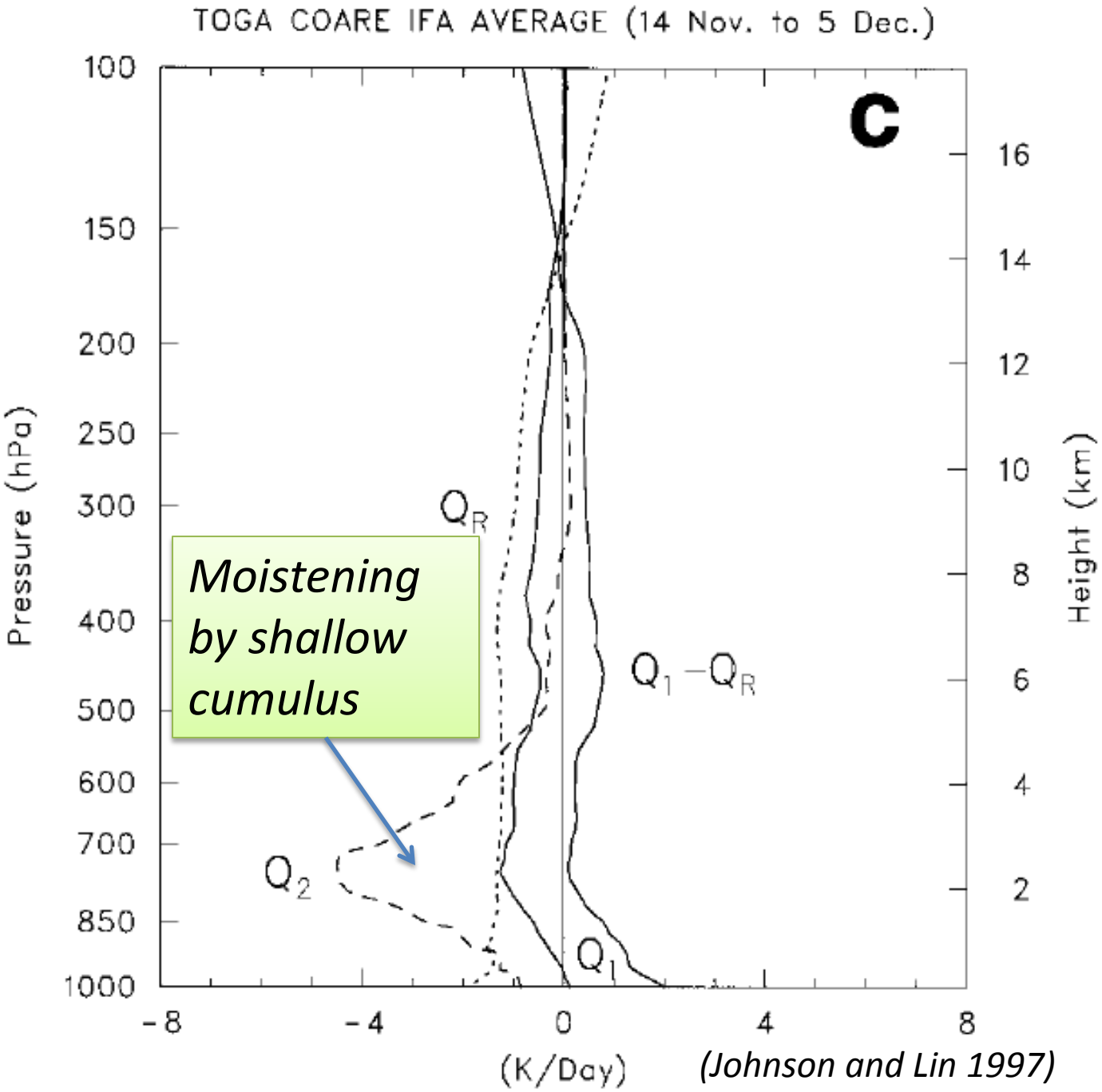


Mesoscale Circulations



Mesoscale circulations promote afternoon isolated cumulus and showers

3 December 1992 – Light-wind day, inactive phase of MJO

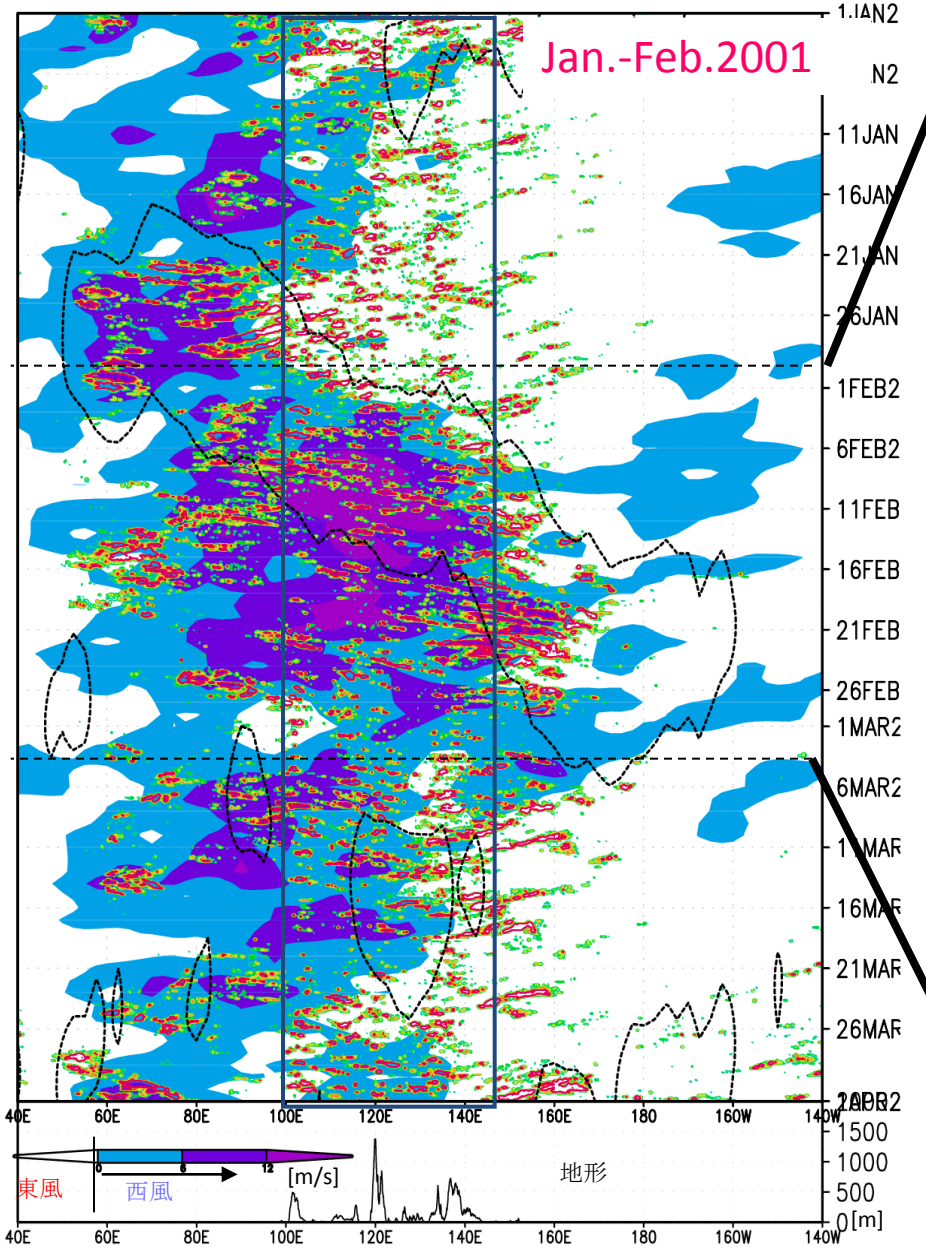


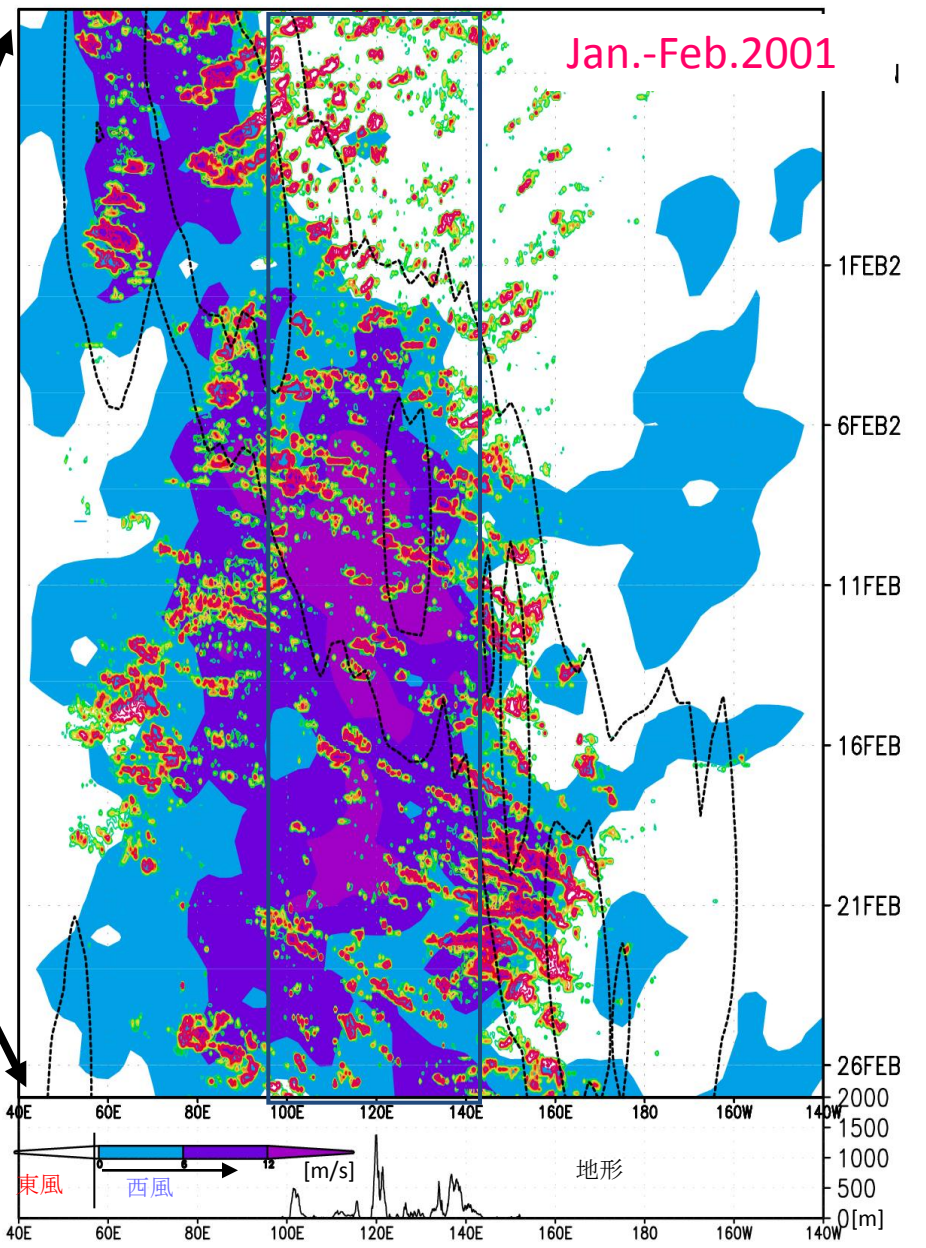
(Johnson and Lin 1997)

Time-long.section of PR, filtered OLR and zonal wind (600hPa)

Ichikawa and Yasunari (2006)

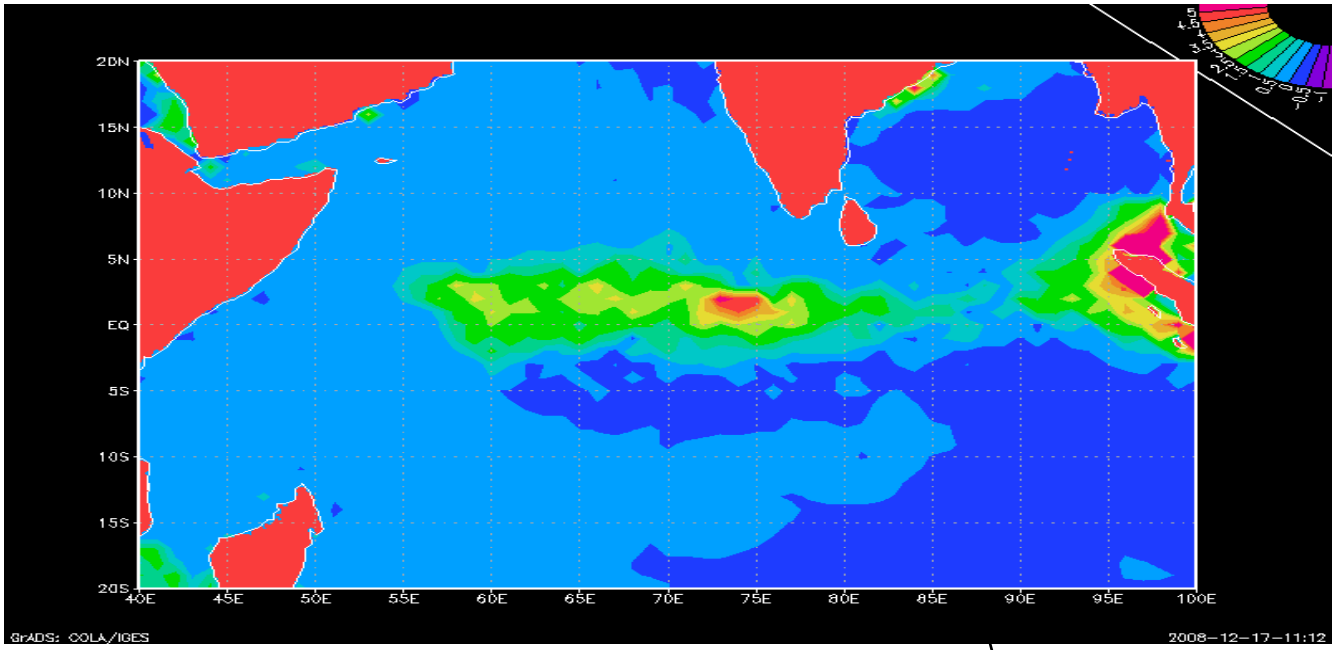
黄~赤線・・・3時間ごとの降雨量　TRMM3B42
(0.4、0.6、0.8、1.0、1.2、1.4、1.6
黒線・・・30-60日フィルタをかけたＯＬＲ(負偏差-5、-20W/
下地・・・600hPa高度の東西風速





The effect of diurnal SST change?

MARIA FLATAU



- Average SST diurnal amplitude August 1-5 2008

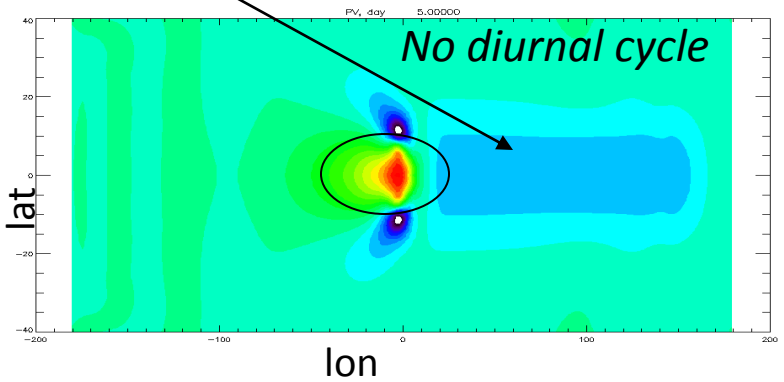
Diurnal warming of “skin SST” as simulated in NOGAPS, using Zeng and Beljaars (2005) scheme

The effect of diurnal SST change on equatorial Kelvin waves

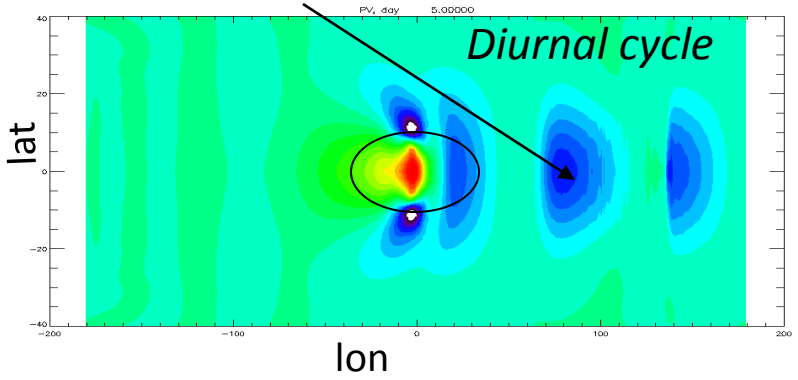
MARIA FLATAU

Shallow water NSEAM

One long wave

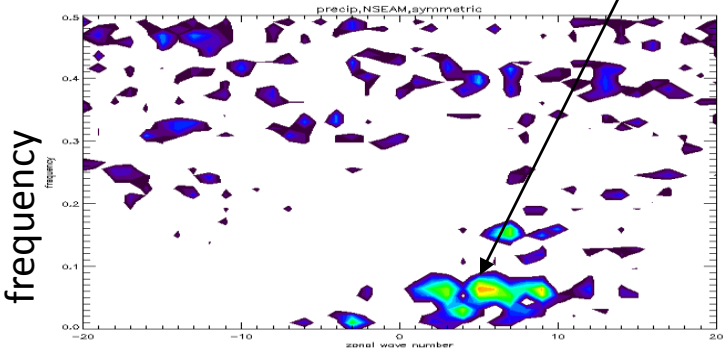


Series of intense short waves

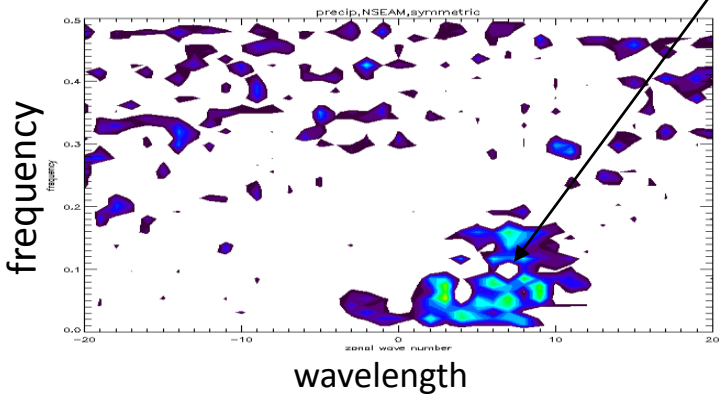


Aqua planet NSEAM

Strong peak for one frequency

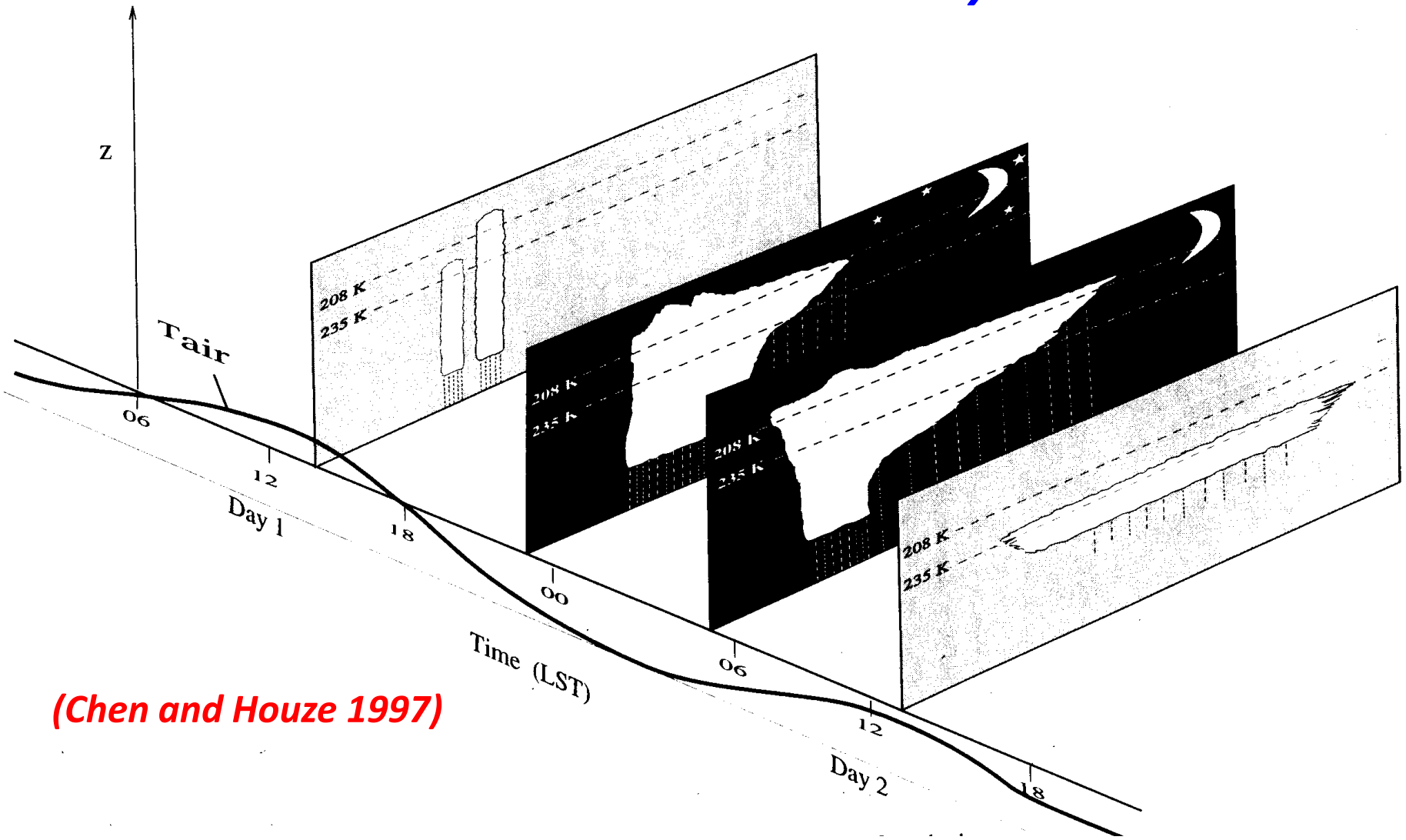


Broad spectrum



NSEAM: Navy Spectral Element Atmospheric Model (Giraldo, 2005)

Coupling of Convection with 2-Day, Westward Inertio-Gravity Waves



(Chen and Houze 1997)

Migrating, Propagating Diurnal Signals

- Over land: commonplace downstream of major mountain ranges
- Over ocean: along coastlines of continents
- Mechanisms: gravity waves, gravity currents, discrete propagation; coherent vortices; other?

Panama Bight: gravity waves (Mapes et al. 2003)

Northern SCS: squall lines – discrete propagation? (Aves and Johnson 2008)

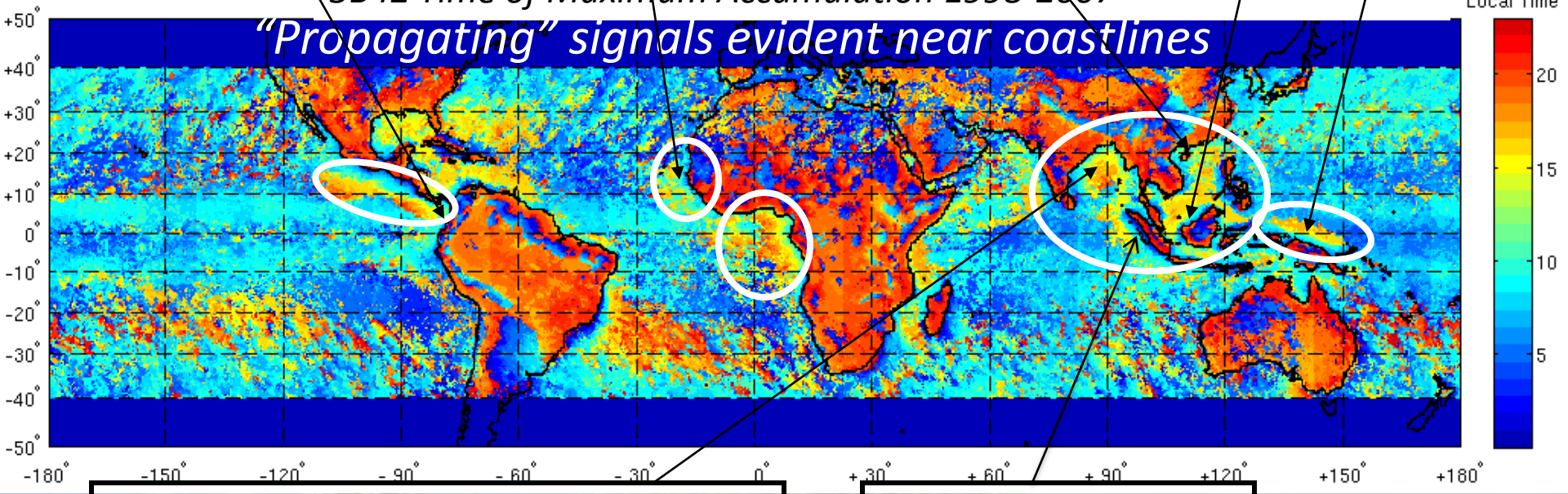
Papua New Guinea: gravity waves (Liberti et al. 2001; Zhou and Wang 2006)

Borneo: (Houze et al. 1981; Ichikawa and Yasunari 2006)

GATE region: squall line propagation from West Africa

3B42 Time of Maximum Accumulation 1998-2007

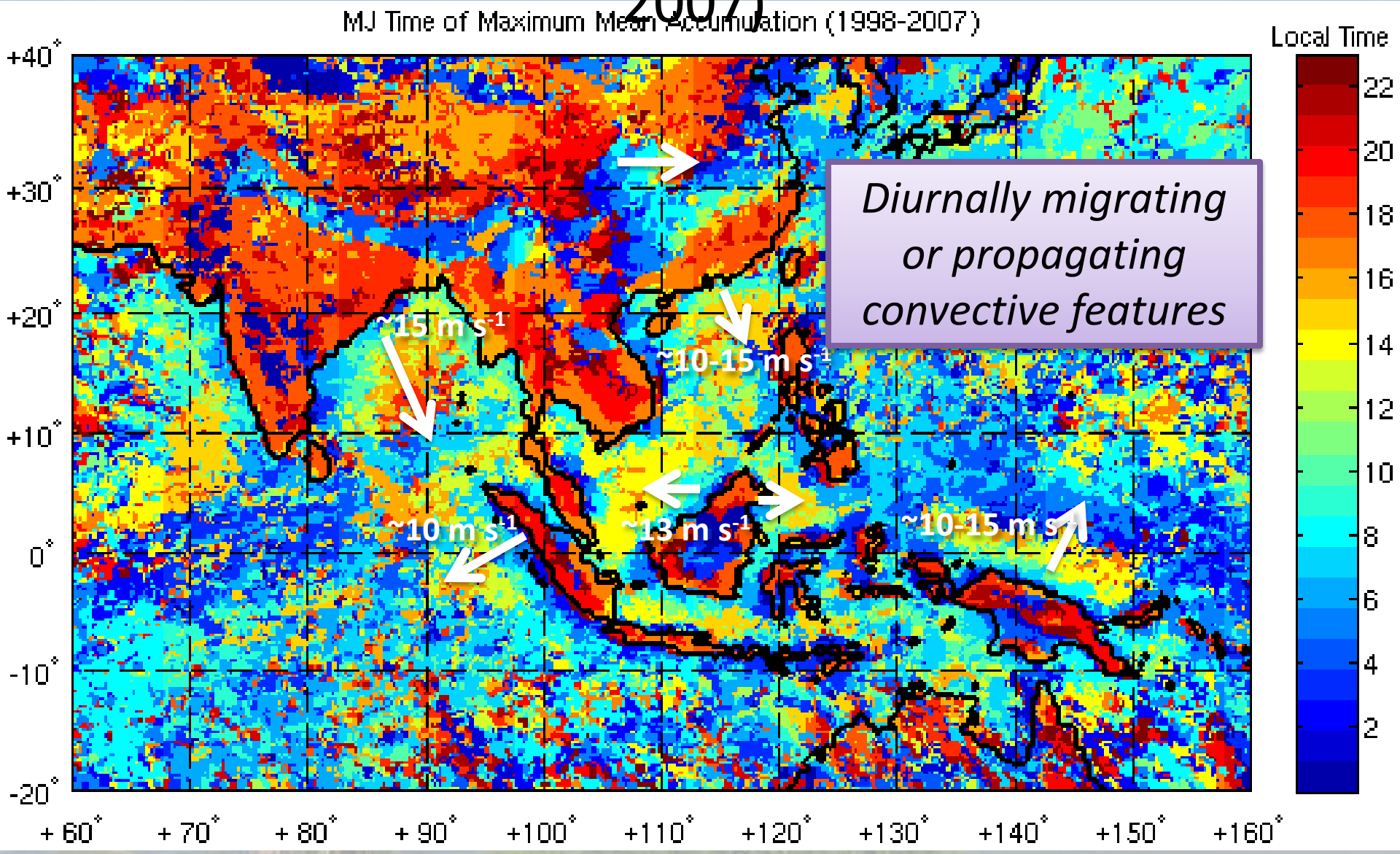
"Propagating" signals evident near coastlines



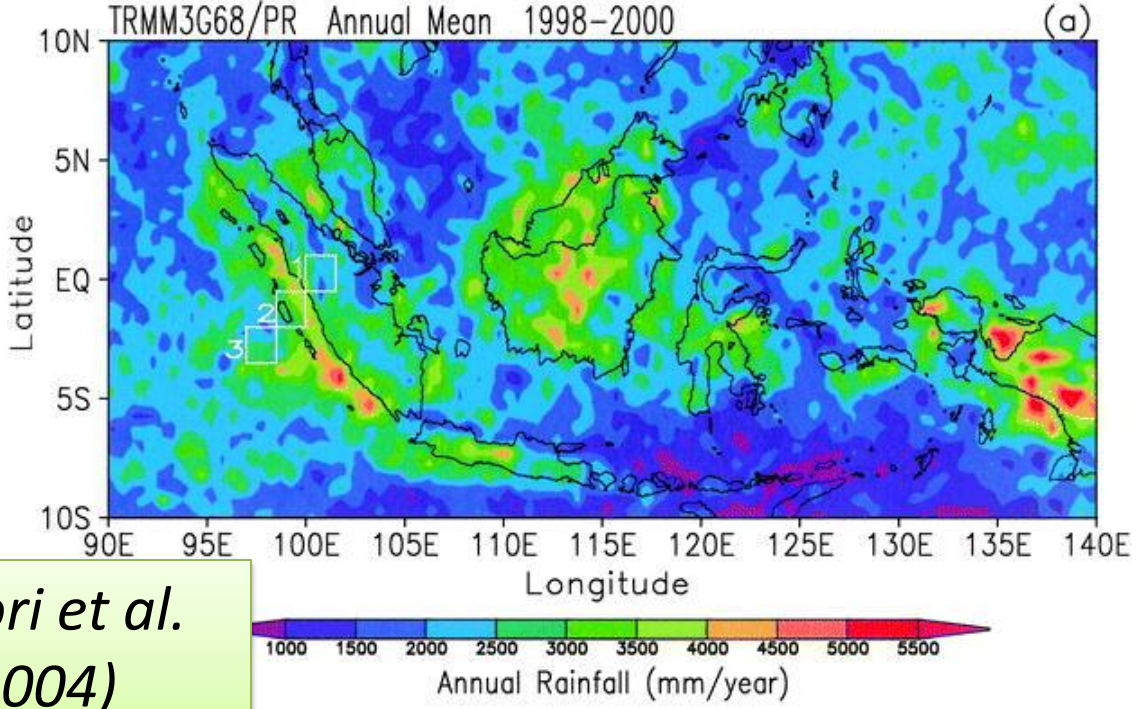
Indian Ocean: squall lines (Yang and Slingo 2001; Webster et al. 2002)

Sumatra (Sakurai et al. 2005)

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

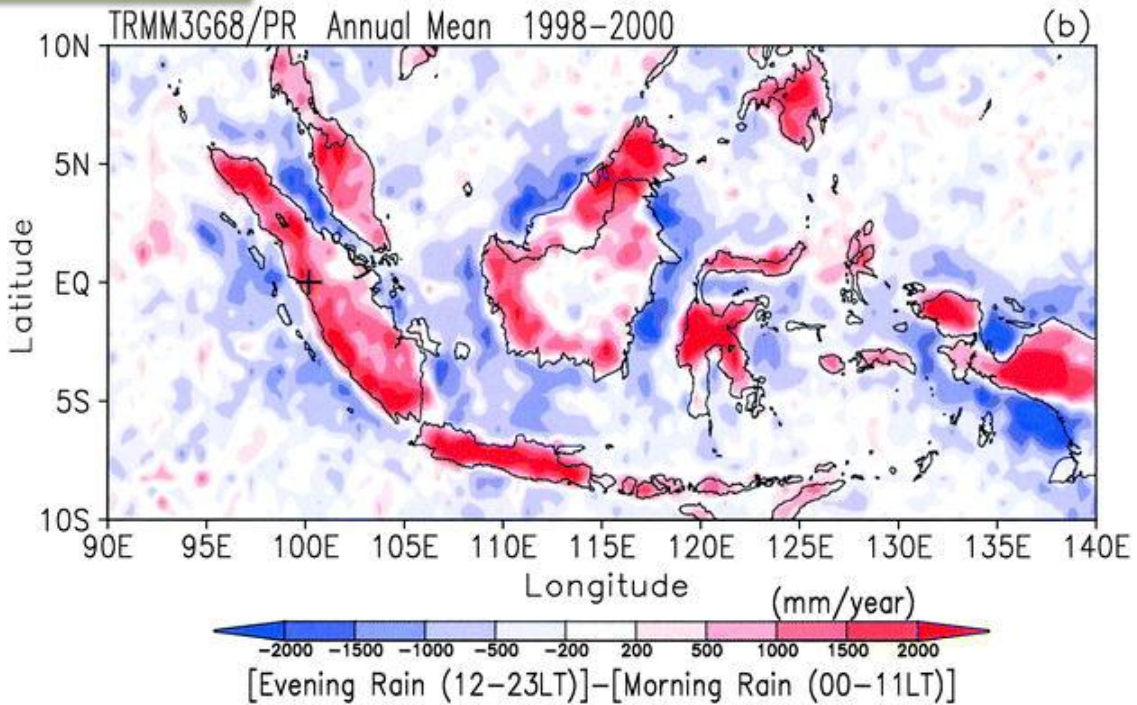


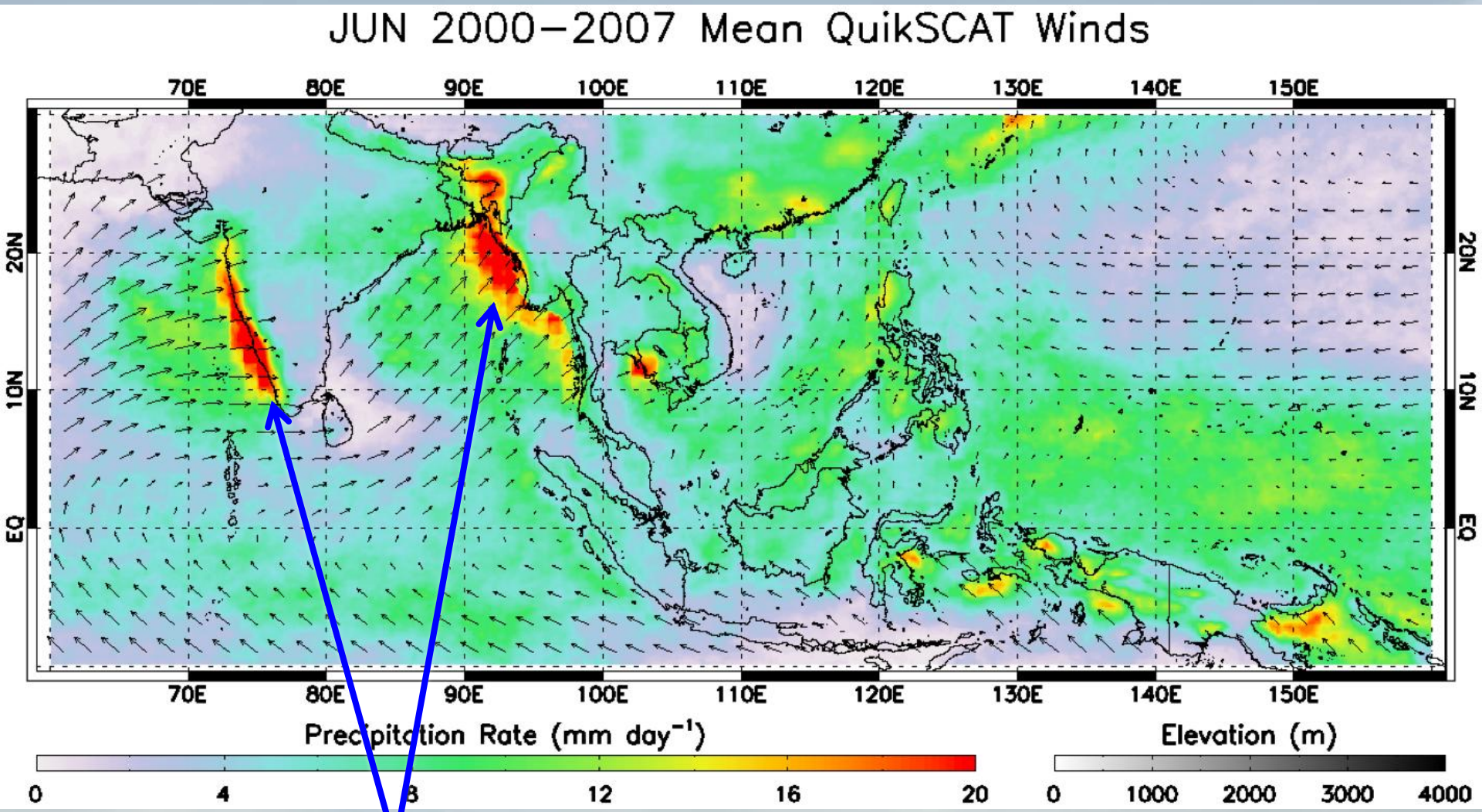
Diurnal cycle over Maritime Continent



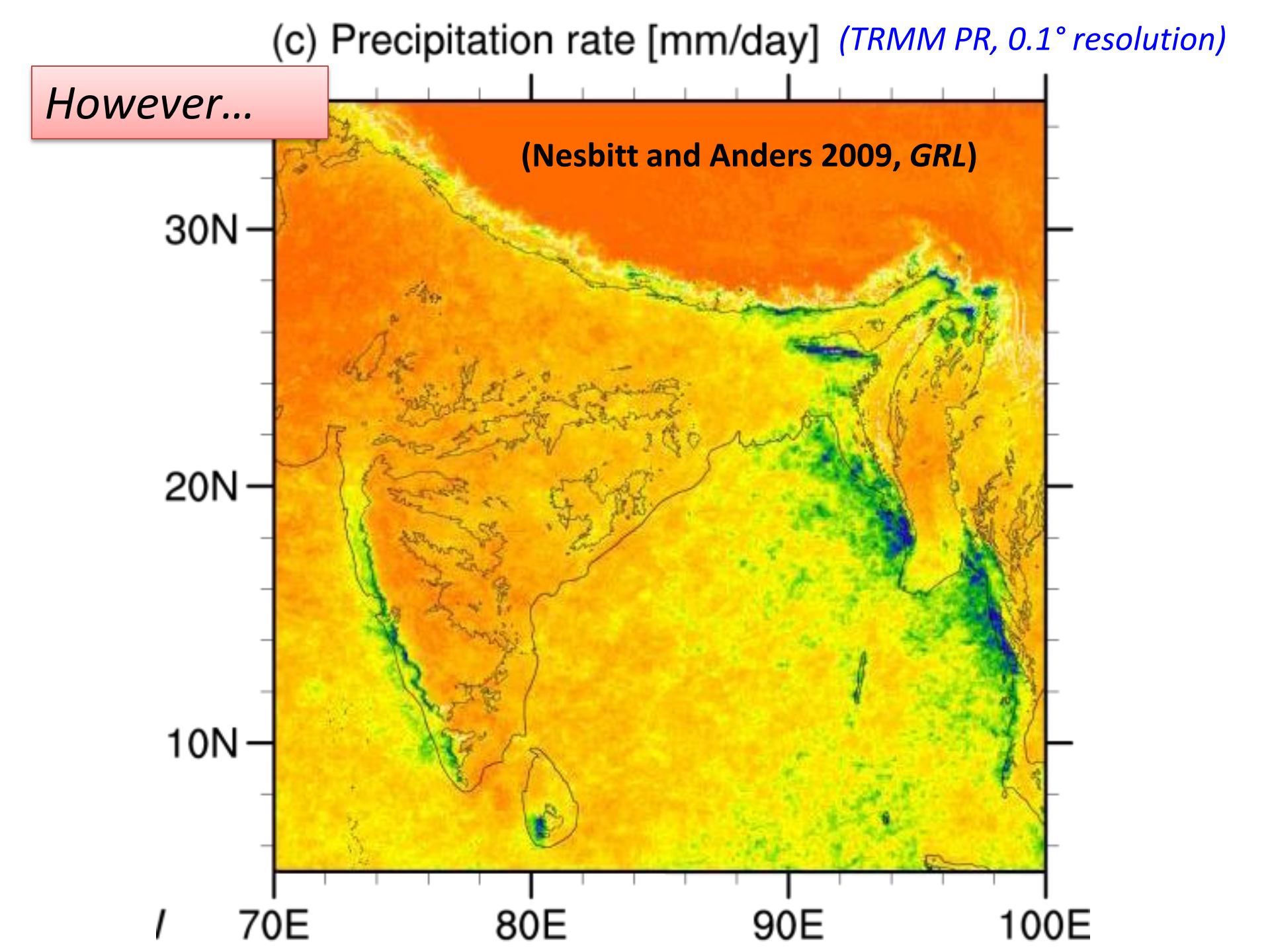
(Mori et al. 2004)

To what extent is amplitude modulated by MJO, ENSO, IOD, …?

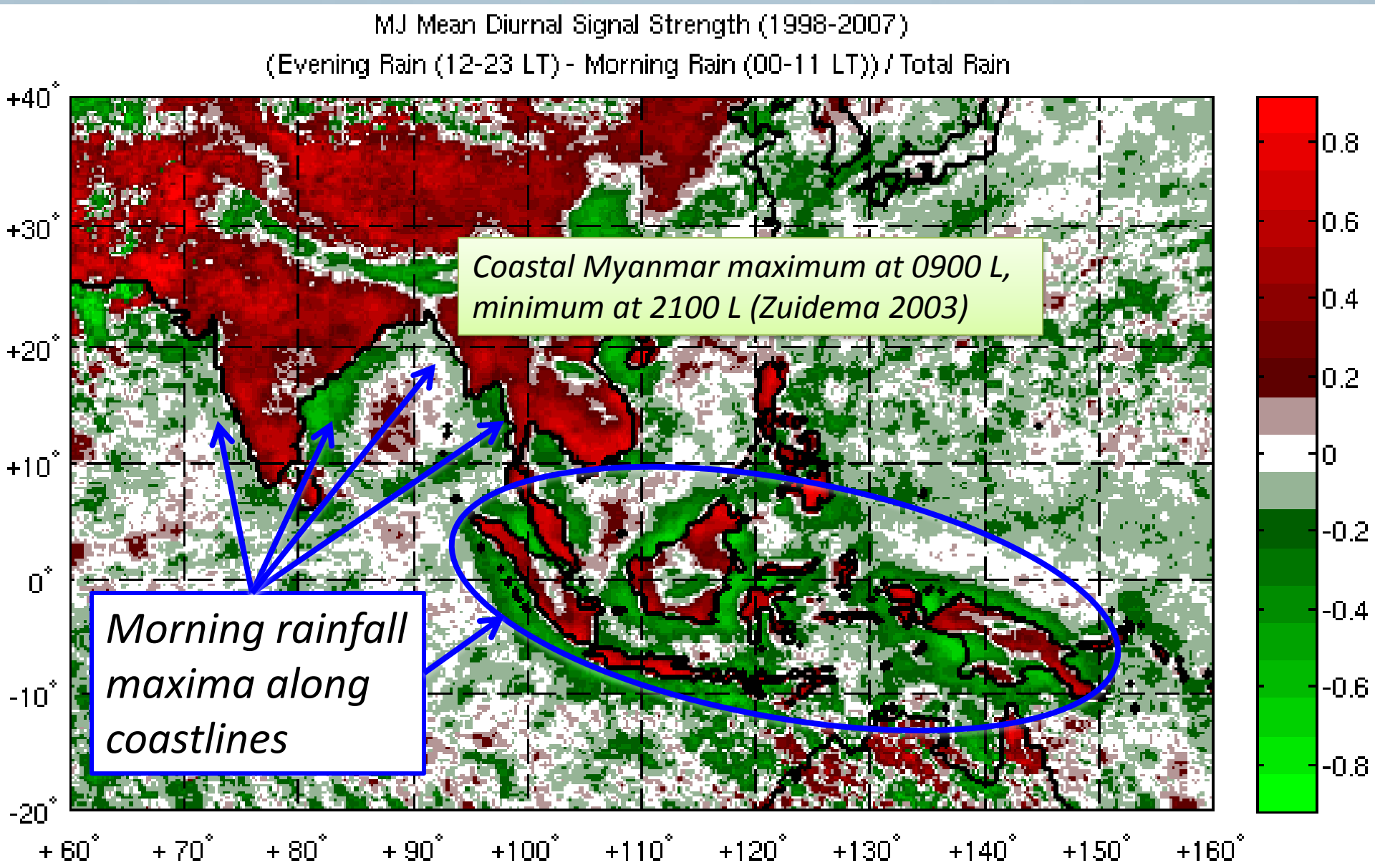




Heaviest rainfall <u>appears</u> to occur just offshore – Western Ghats and Myanmar – not over coastal mountain ranges


(c) Precipitation rate [mm/day] (TRMM PR, 0.1° resolution)
However…
(Nesbitt and Anders 2009, GRL)
30N
20N
10N
70E
80E
90E
100E

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



Preliminary Results from the SoWMEX/TiMREX Sounding Network

Richard H. Johnson
Paul E. Ciesielski

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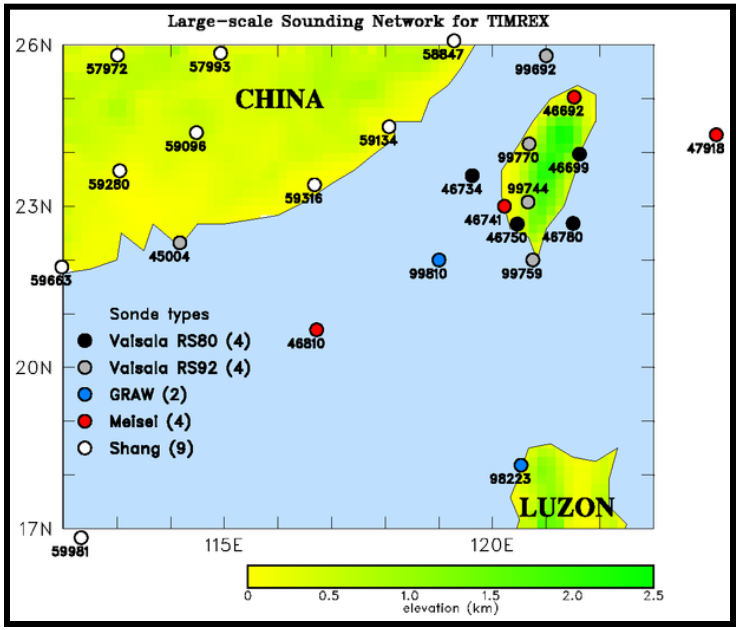
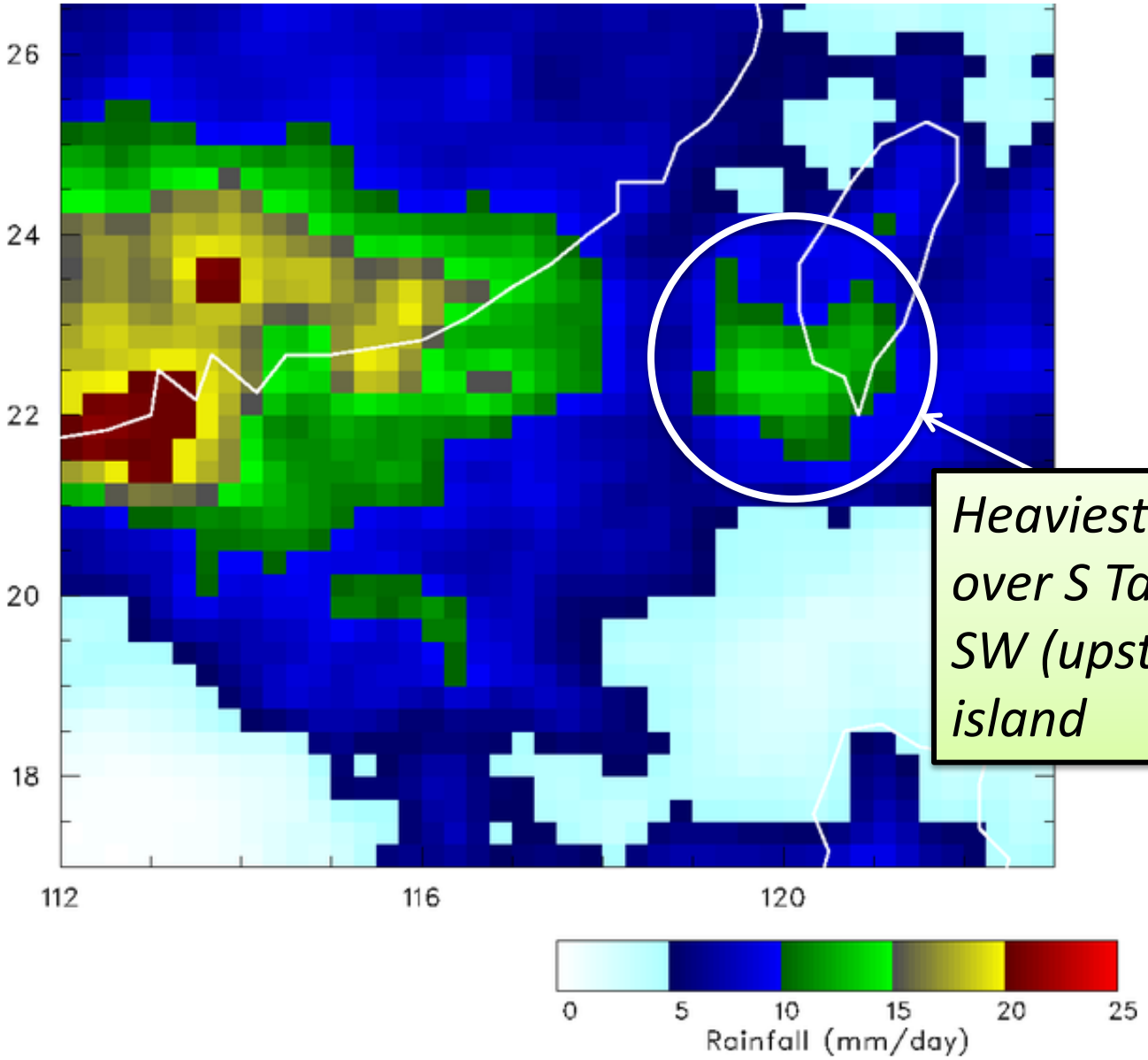


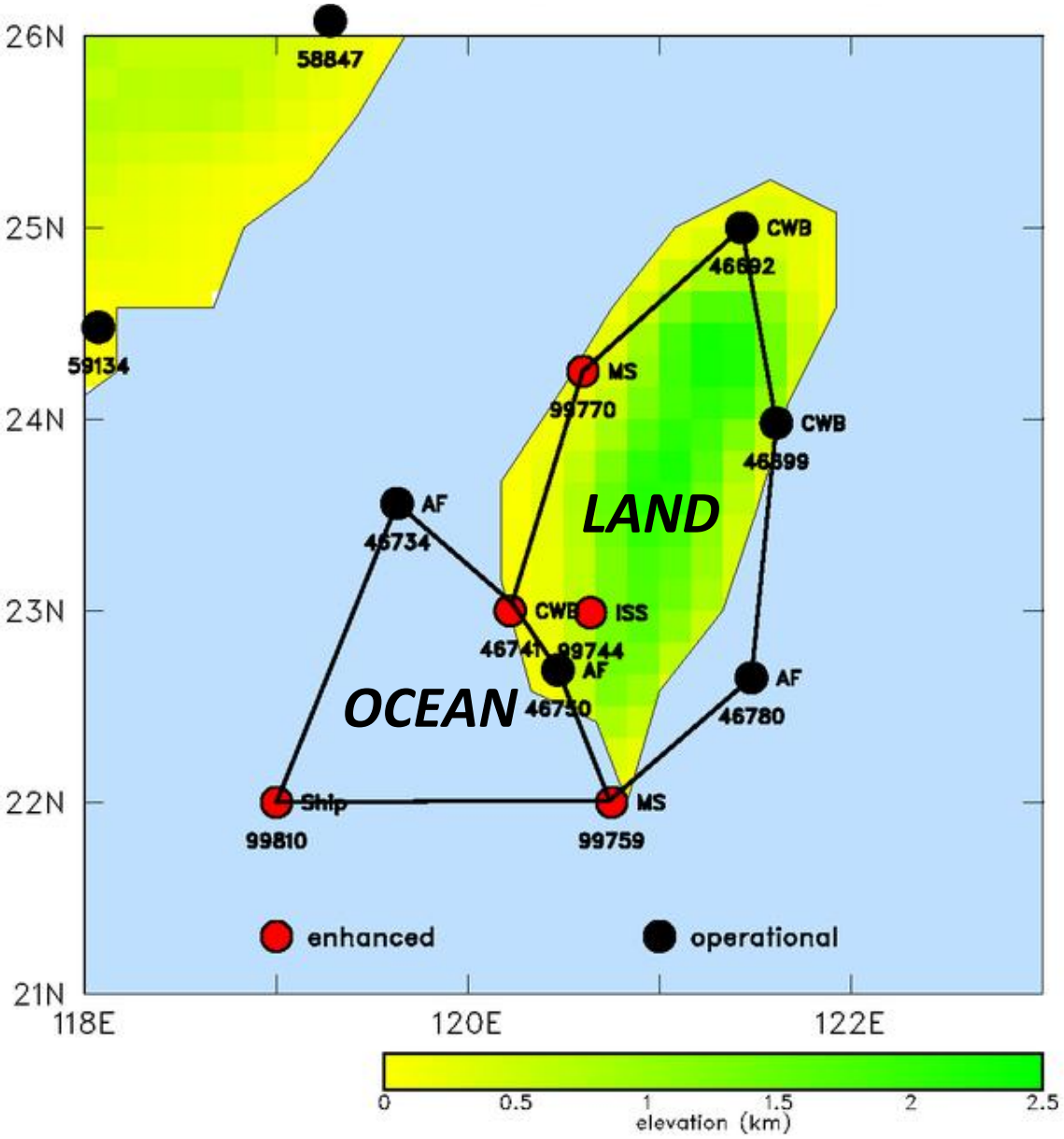
Southwest Monsoon Experiment 2008
Terrain-influenced Monsoon Rainfall Experiment
SoWMEX TIMREX

TRMM 3B42 TiMREX Average Rainfall *(mm/day)*

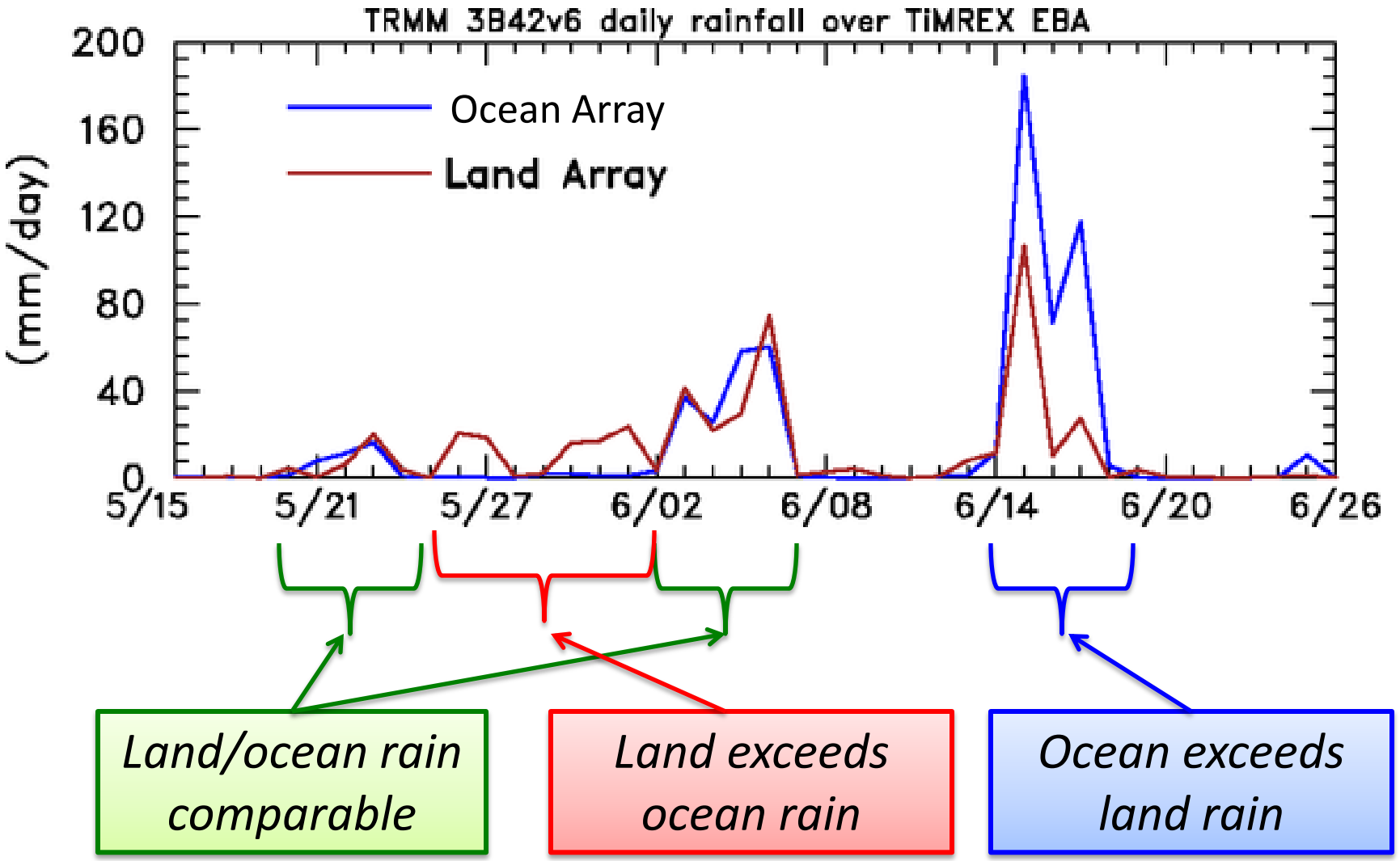
15 May – 26 June 2008



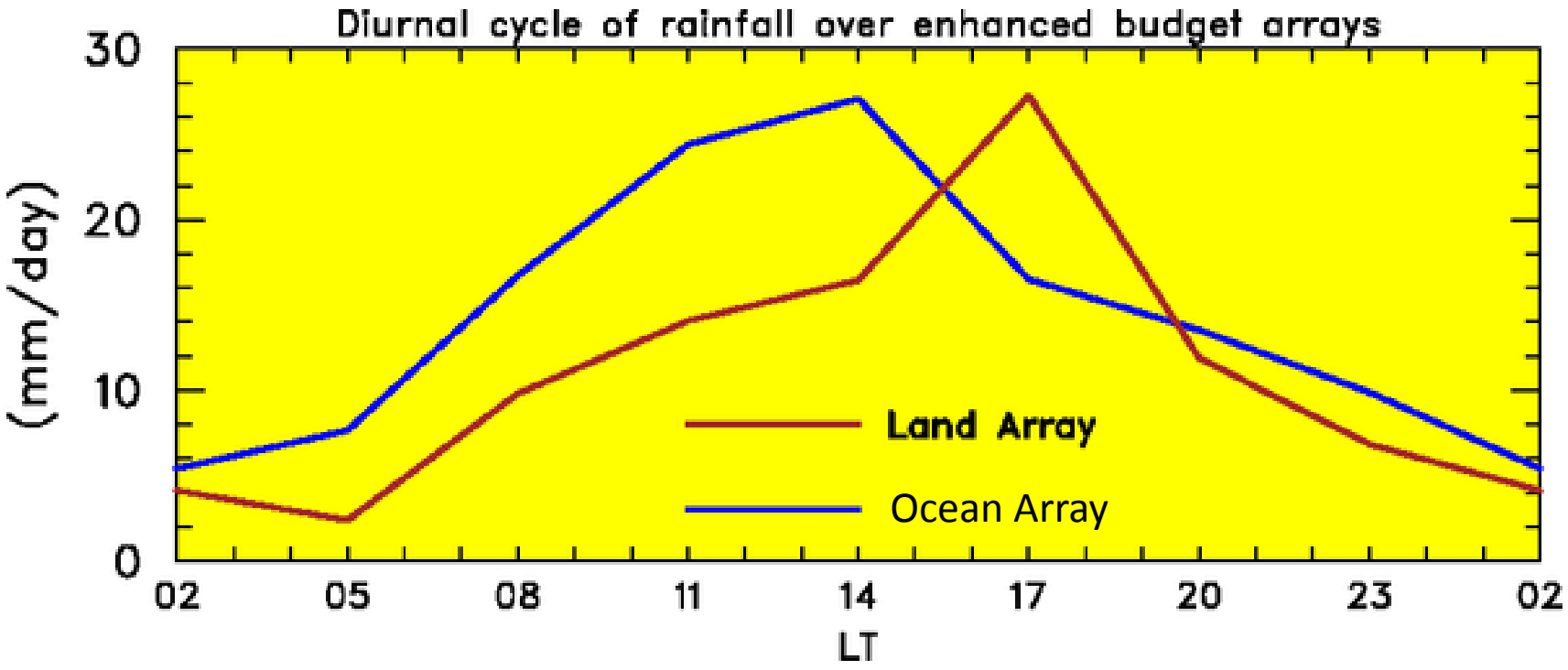
SoWMEX/TiMREX Sounding Arrays



Land/Ocean Rainfall Time Series



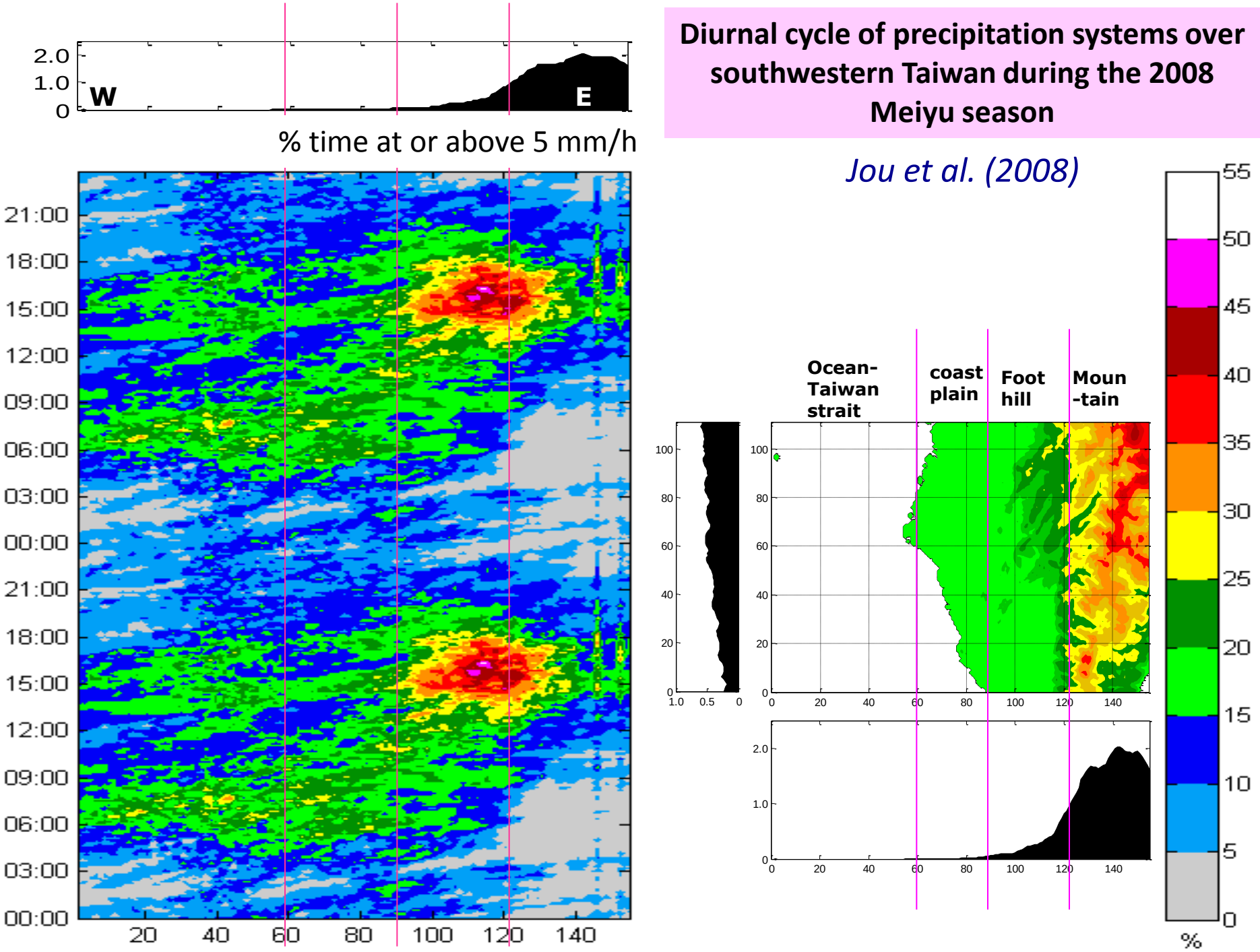
Mean Diurnal Cycle of Rainfall



- *Afternoon/evening rainfall maximum over land*
- *Mid-day maximum in rainfall over ocean*

Diurnal cycle of precipitation systems over southwestern Taiwan during the 2008 Meiyu season

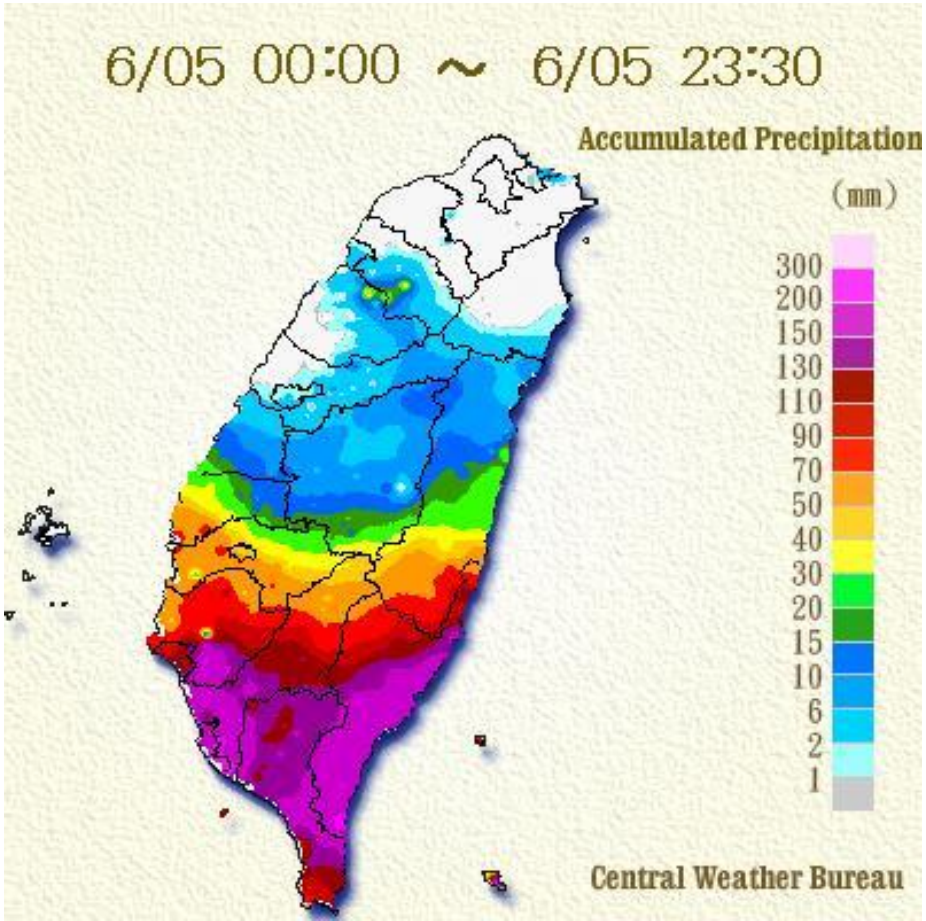
Jou et al. (2008)



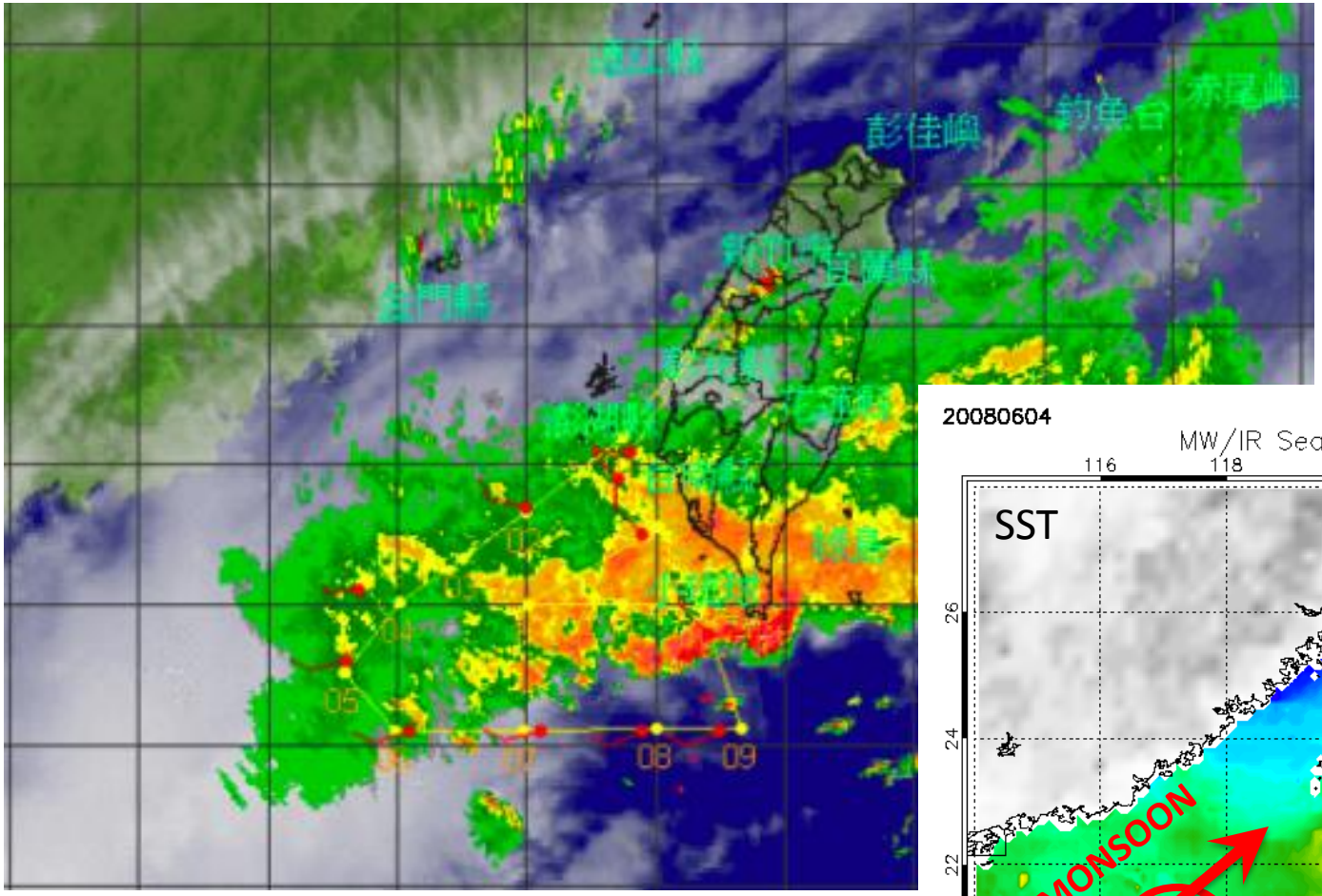
IOP-5,6

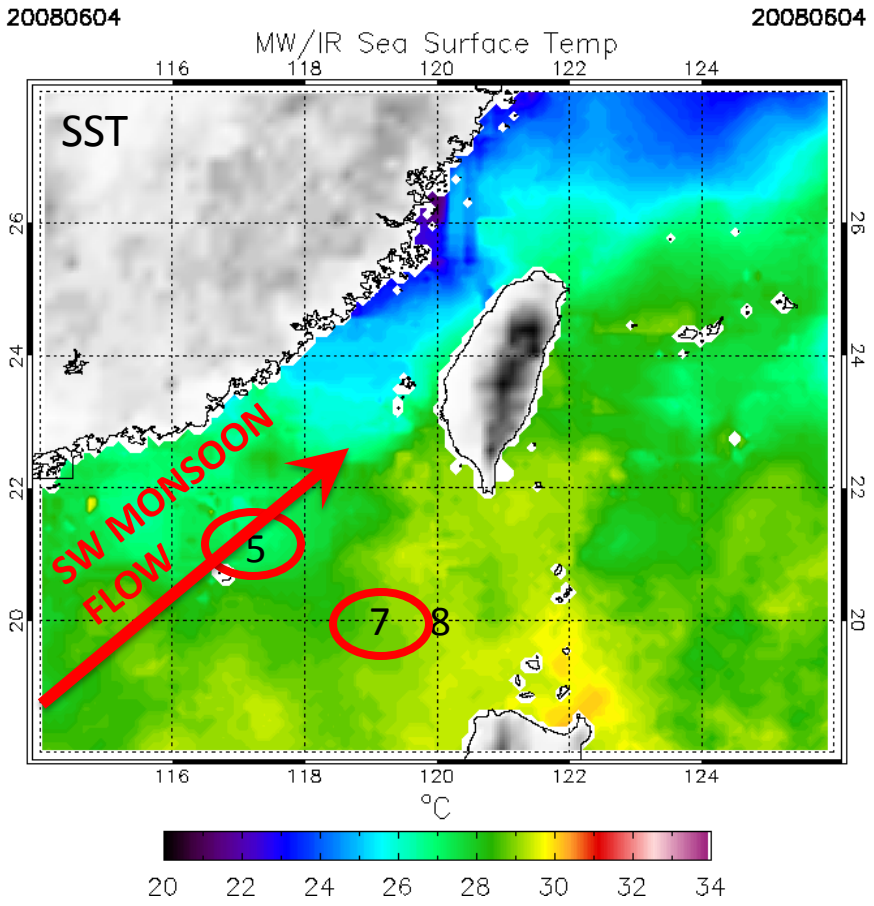
Heavy Rainfall Southern Taiwan; Weak Depression along Meiyu Front

5 June (UTC)



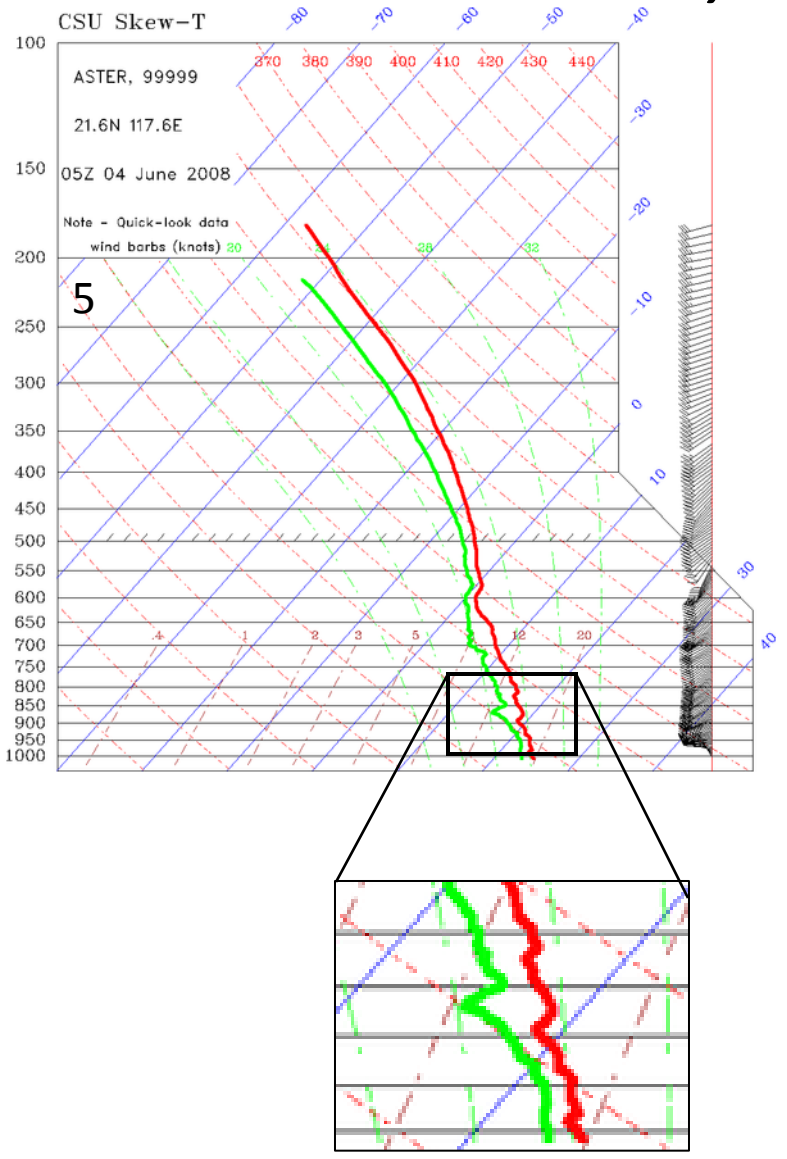
Dropsonde mission on 4 June 2008 (11 LT takeoff)

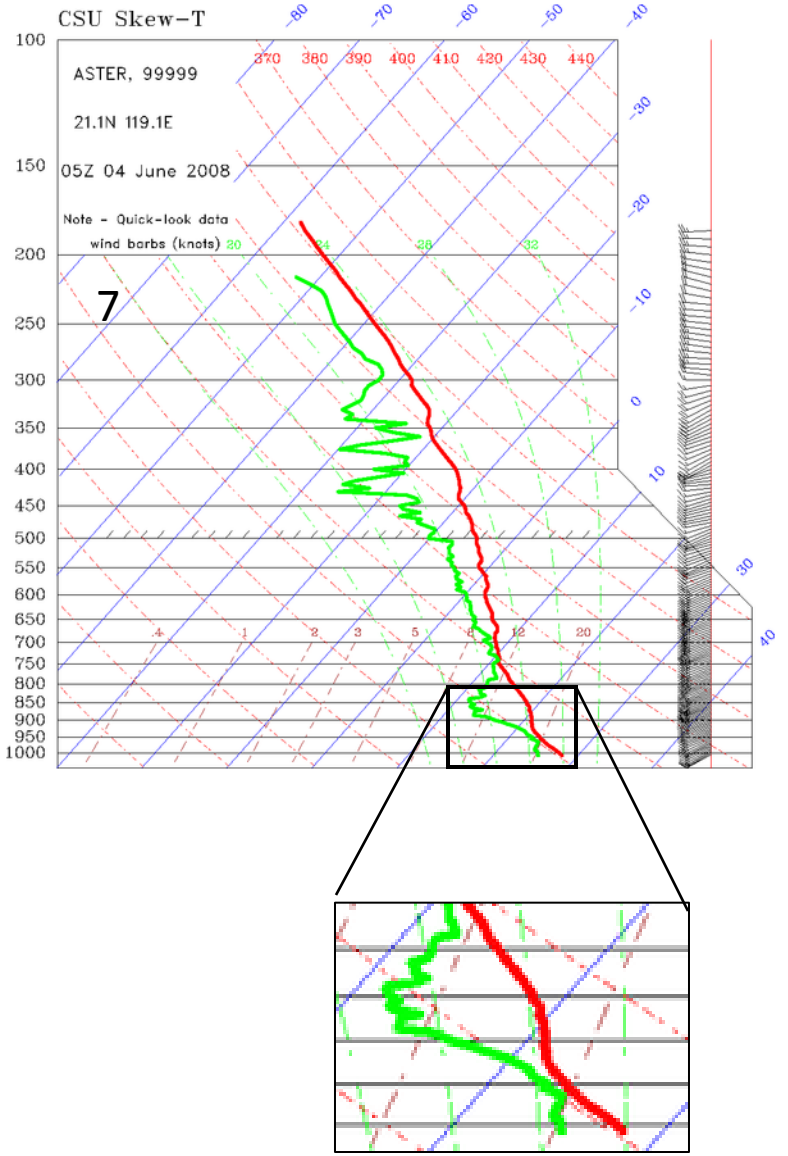




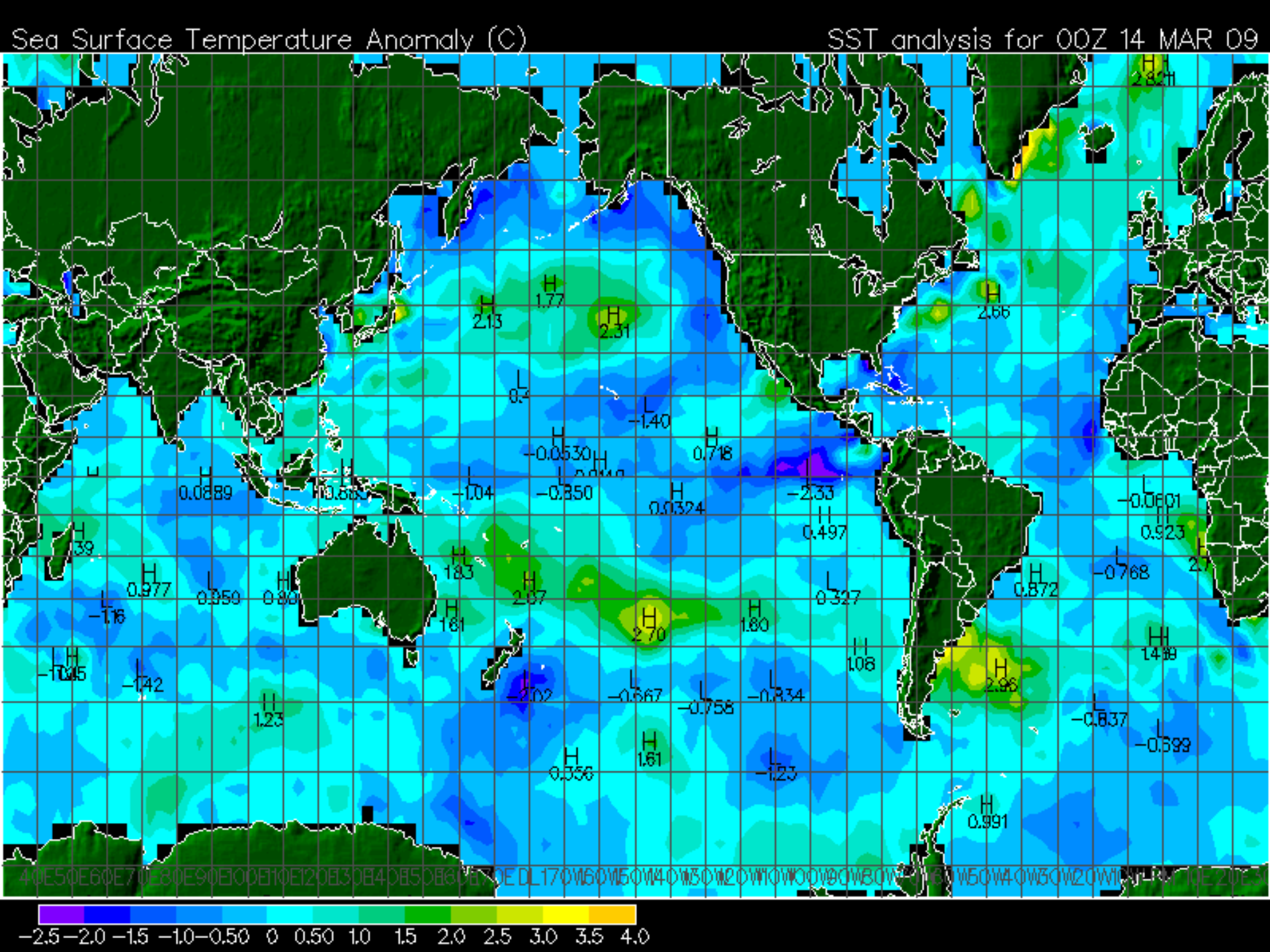
Only sondes 7 and 8 from this flight of 12 dropsondes showed a mixed layer structure; 7 and 8 occurred over warmer SSTs.

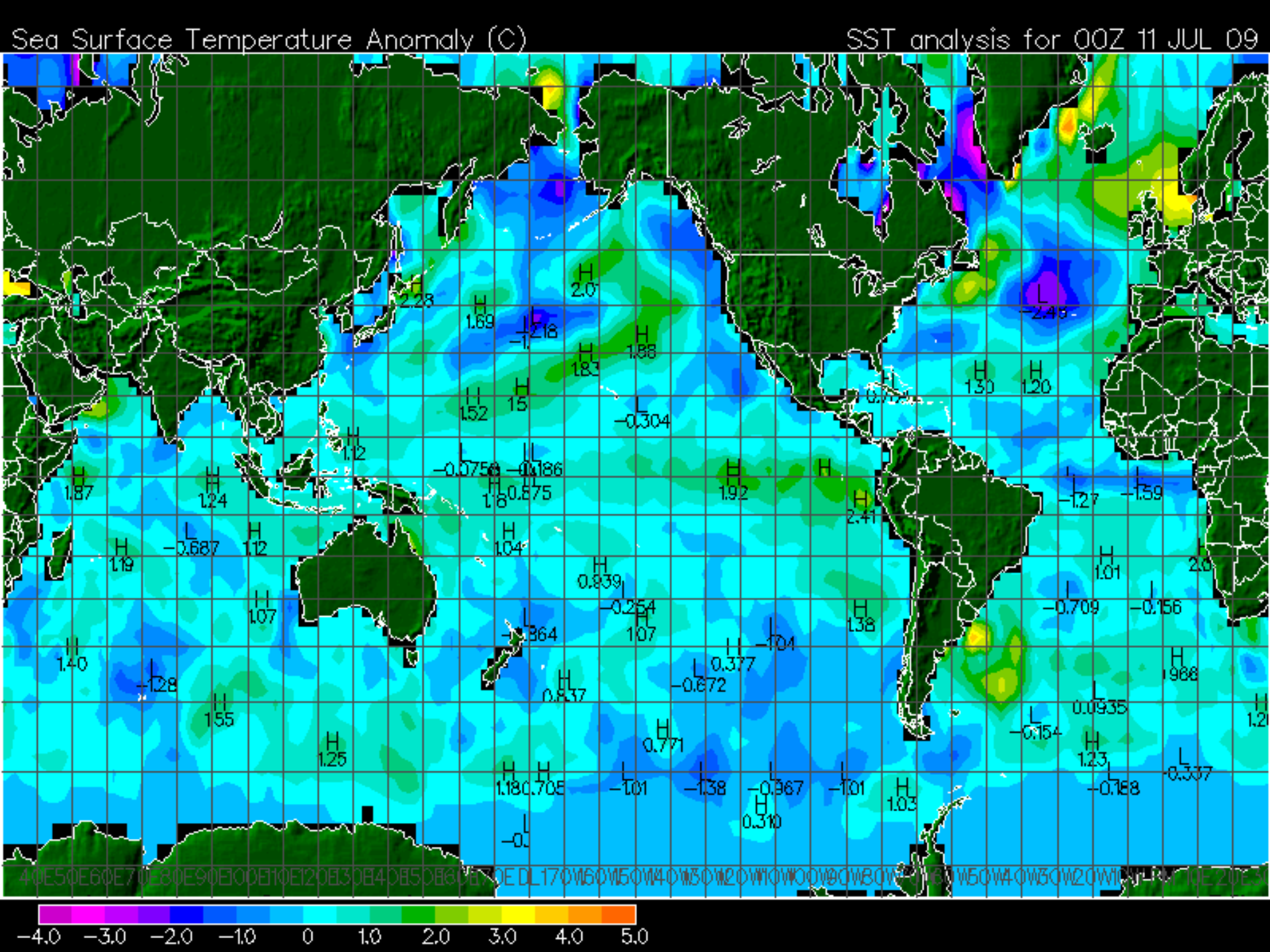
Example of dropsondes without (#5) and with (#7) a mixed layer structure

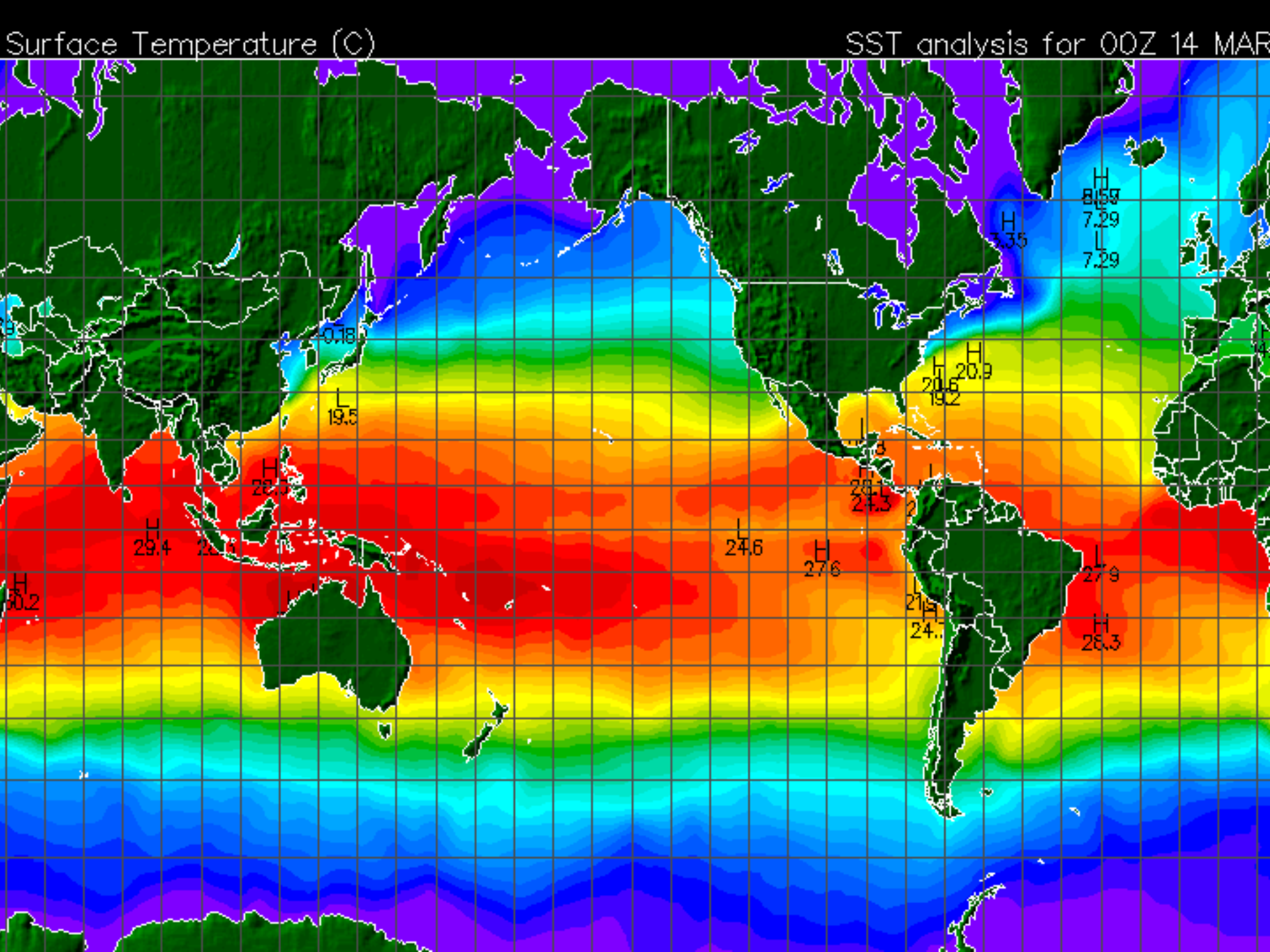


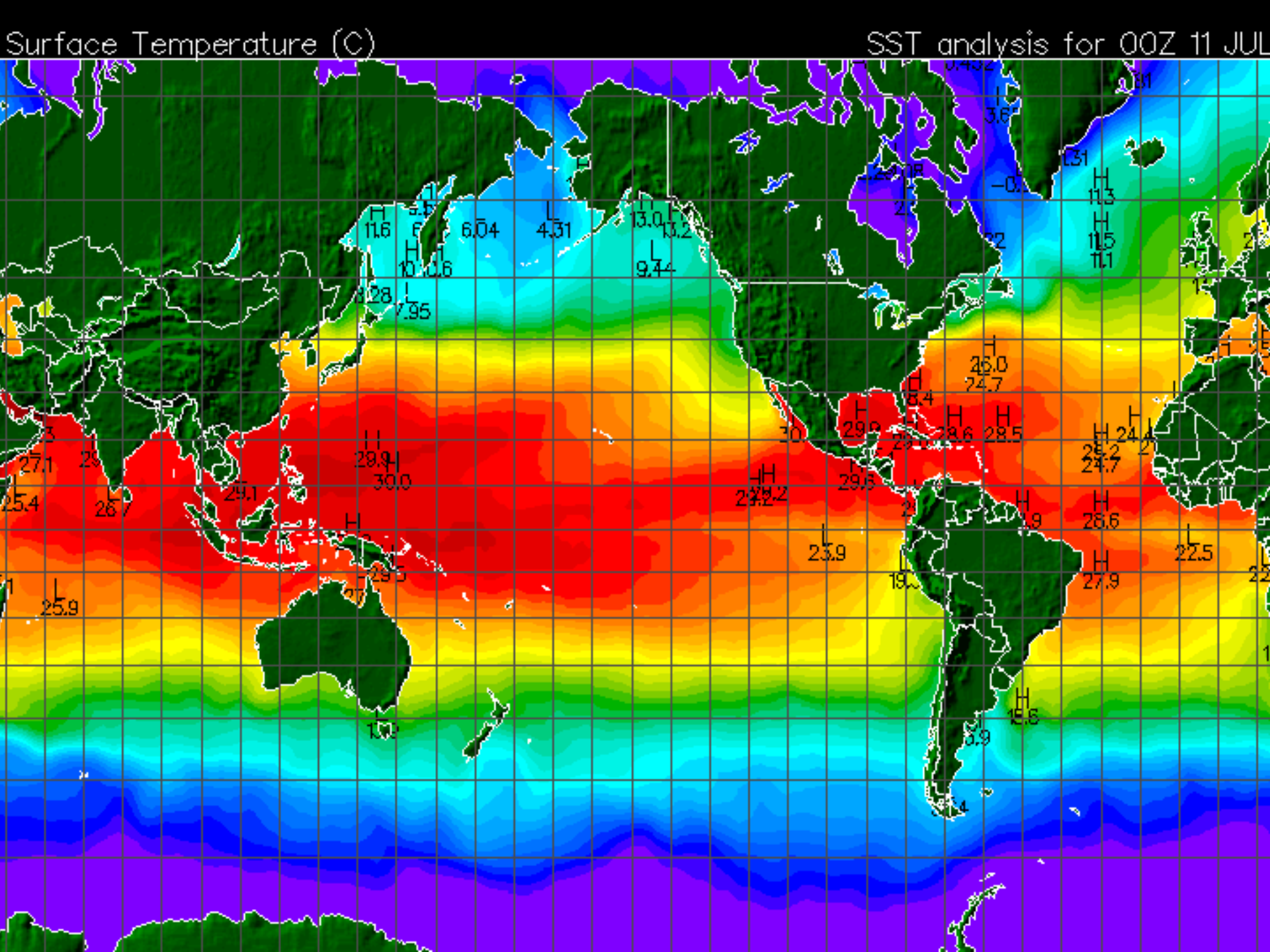



ASTER dropsonde mission on 31 May 2008, Taiwan Straits
Photo by Paul Ciesielsk


Sea Surface Temperature Anomaly (C)
SST analysis for 00Z 14 MAR 09
−2.5 −2.0 −1.5 −1.0 −0.50 0 0.50 1.0 1.5 2.0 2.5 3.0 3.5 4.0

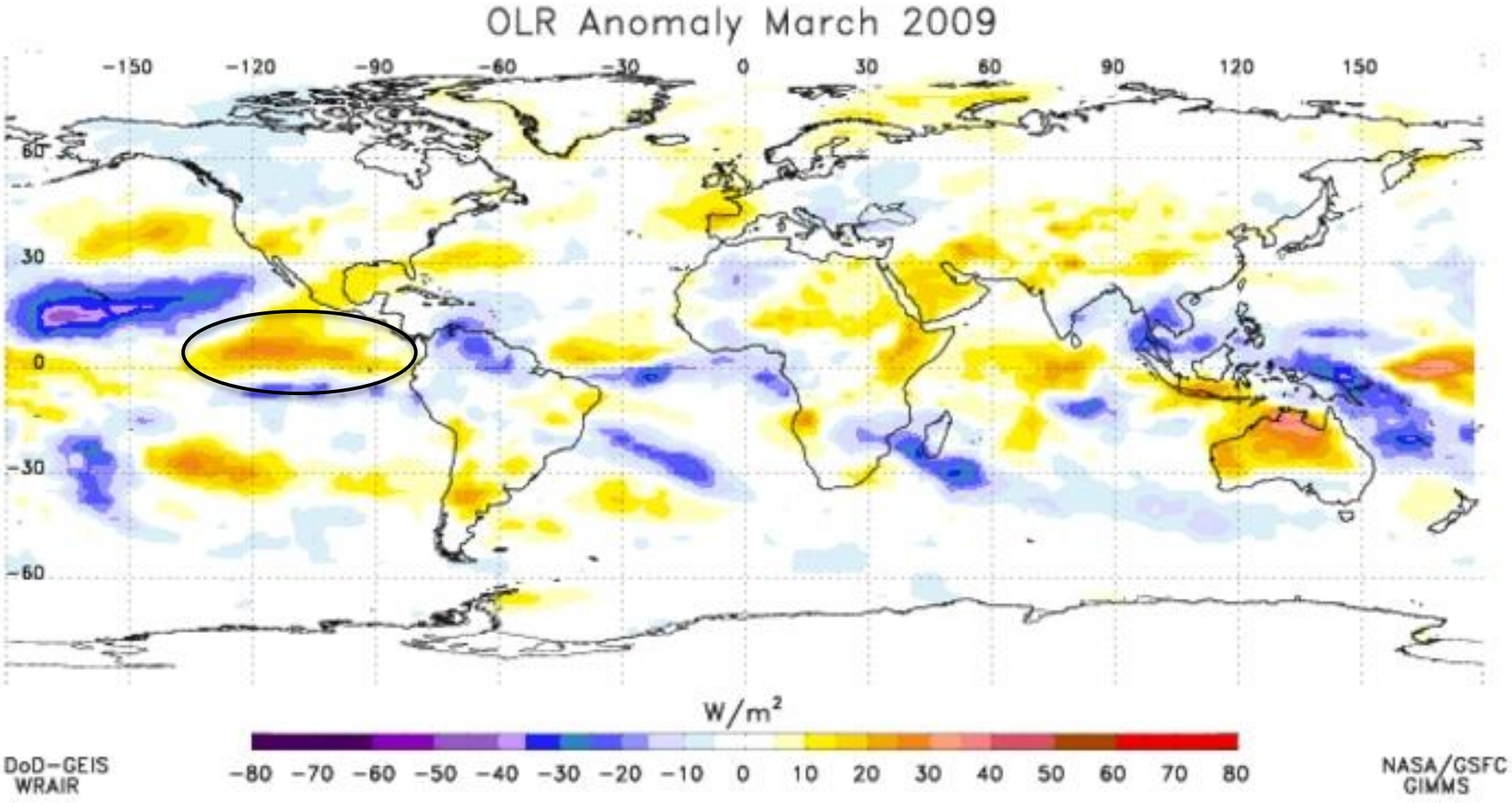

Sea Surface Temperature Anomaly (C)
SST analysis for 00Z 11 JUL 09
−4.0 −3.0 −2.0 −1.0 0 1.0 2.0 3.0 4.0 5.0


Surface Temperature (C)
SST analysis for 00Z 14 MAR
H
3.35
H
7.29
L
7.29
H
20.9
20.6
19.2
L
19.5
H
28.3
29.4
H
30.2
24.3
24.6
H
27.6
27.9
H
28.3

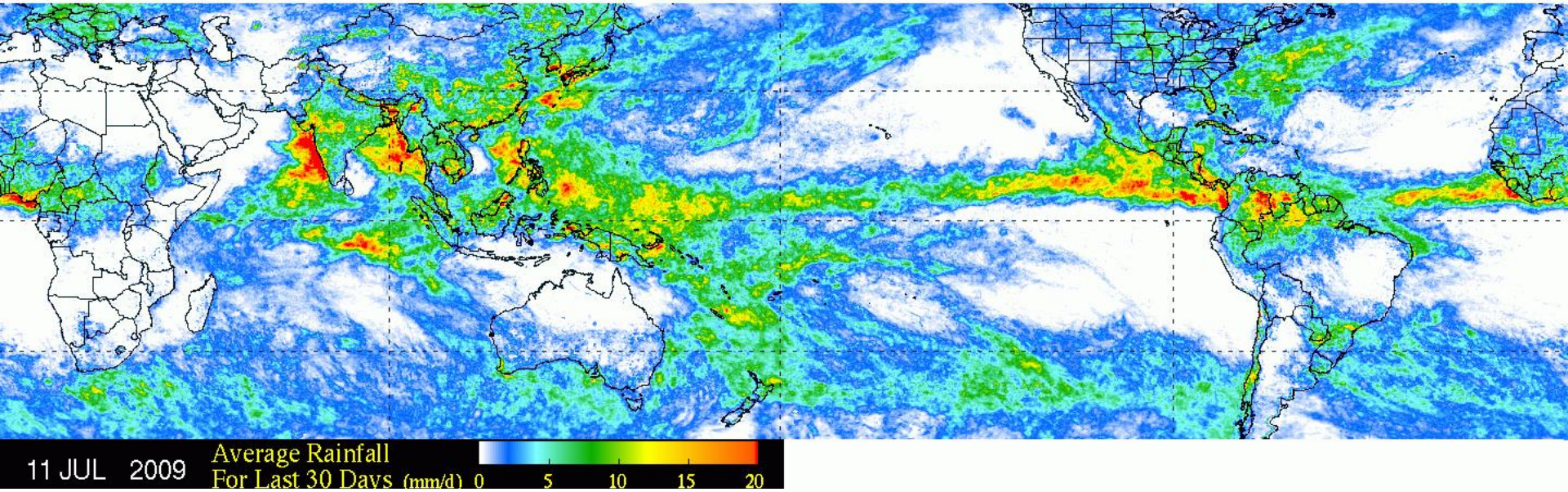

Surface Temperature (C)
SST analysis for 00Z 11 JUL

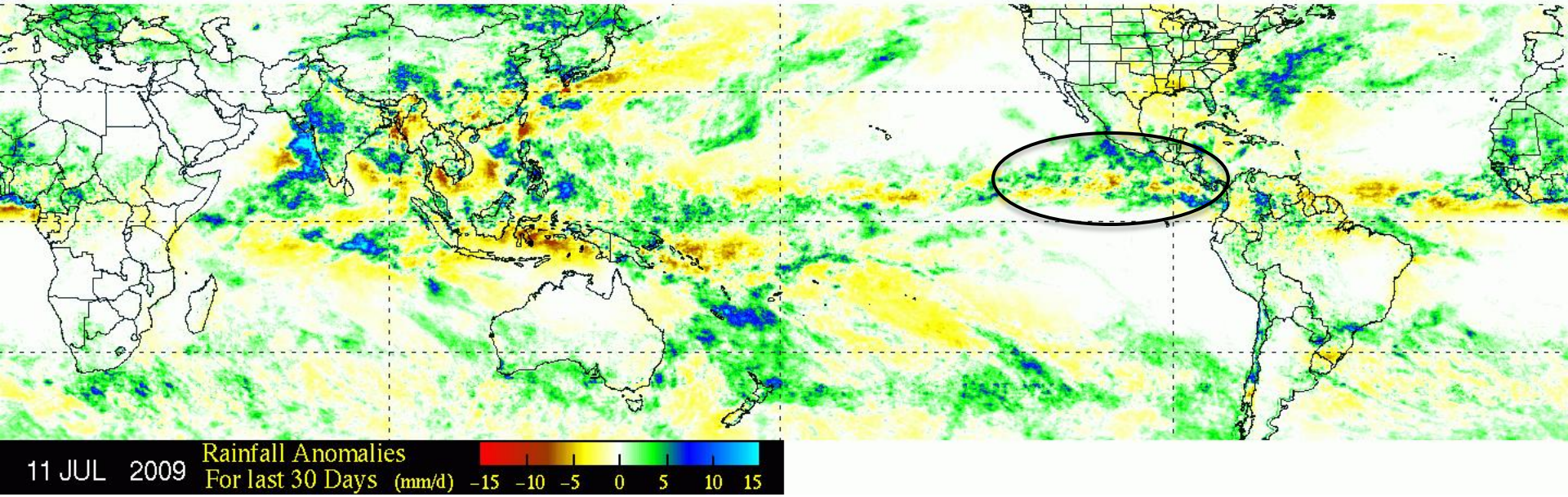
Potential Diurnal Cycle Foci for YOTC

- Diurnal cycle over open ocean
- Impact of diurnal cycle on tropical waves (convectively coupled waves)
- Migrating, propagating diurnal signals over ocean near continents
- Diurnal cycle over maritime continent; modulation by the MJO, ENSO, IOD, other
- Diurnal cycle of convection over West Africa, coupling with AEWs
- Role of diurnal cycle in extreme rainfall along coastlines in monsoon regions (e.g., May-June 2008 SoWMEX/TiMREX)
- Diurnal cycle and development of 2009 El Niño


OLR Anomaly March 2009
-150
-120
-90
-60
-30
0
30
60
90
120
150
60
30
0
-30
-60
W/m²
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80
DoD-GEIS
WRAIR
NASA/GSFC
GIMMS

TRMM 30-day Rainfall and Anomalies Ending 11 July 2009





- What are the characteristics of the diurnal cycle across the equatorial Pacific and does this cycle change in connection with development of El Niño?

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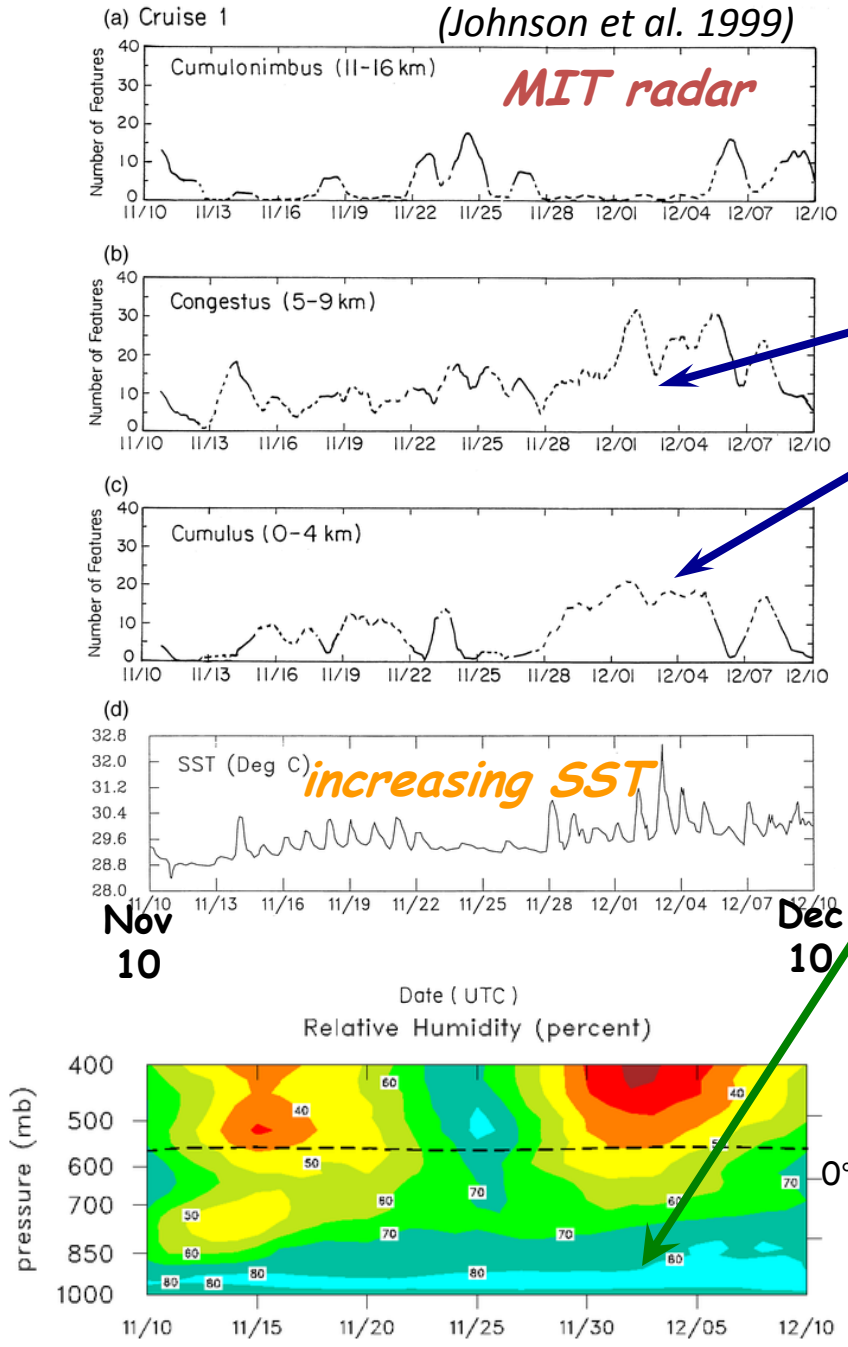


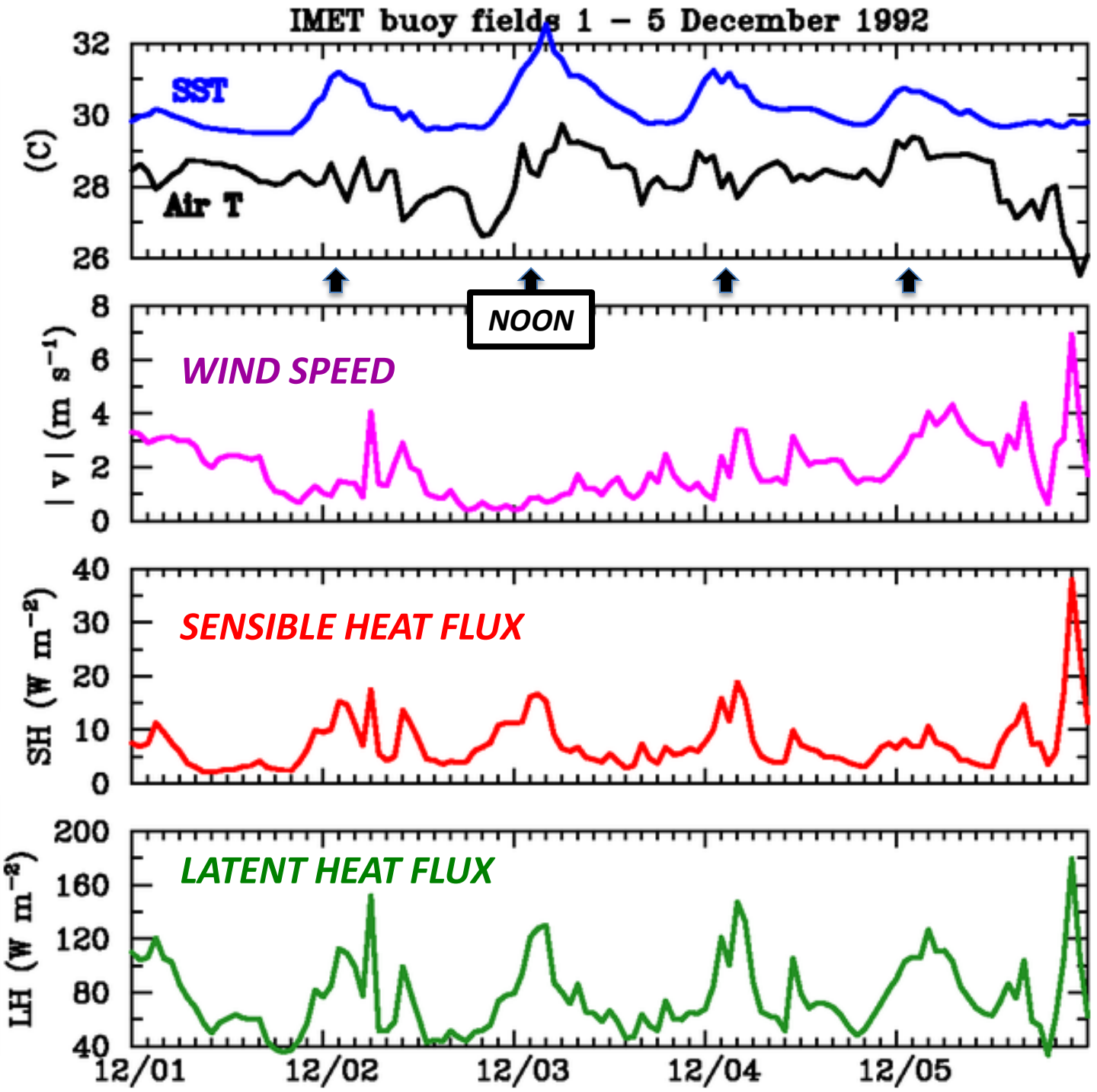
Increasing populations of congestus and cumulus clouds…

moisten the lower troposphere…

preconditioning it for deep convection

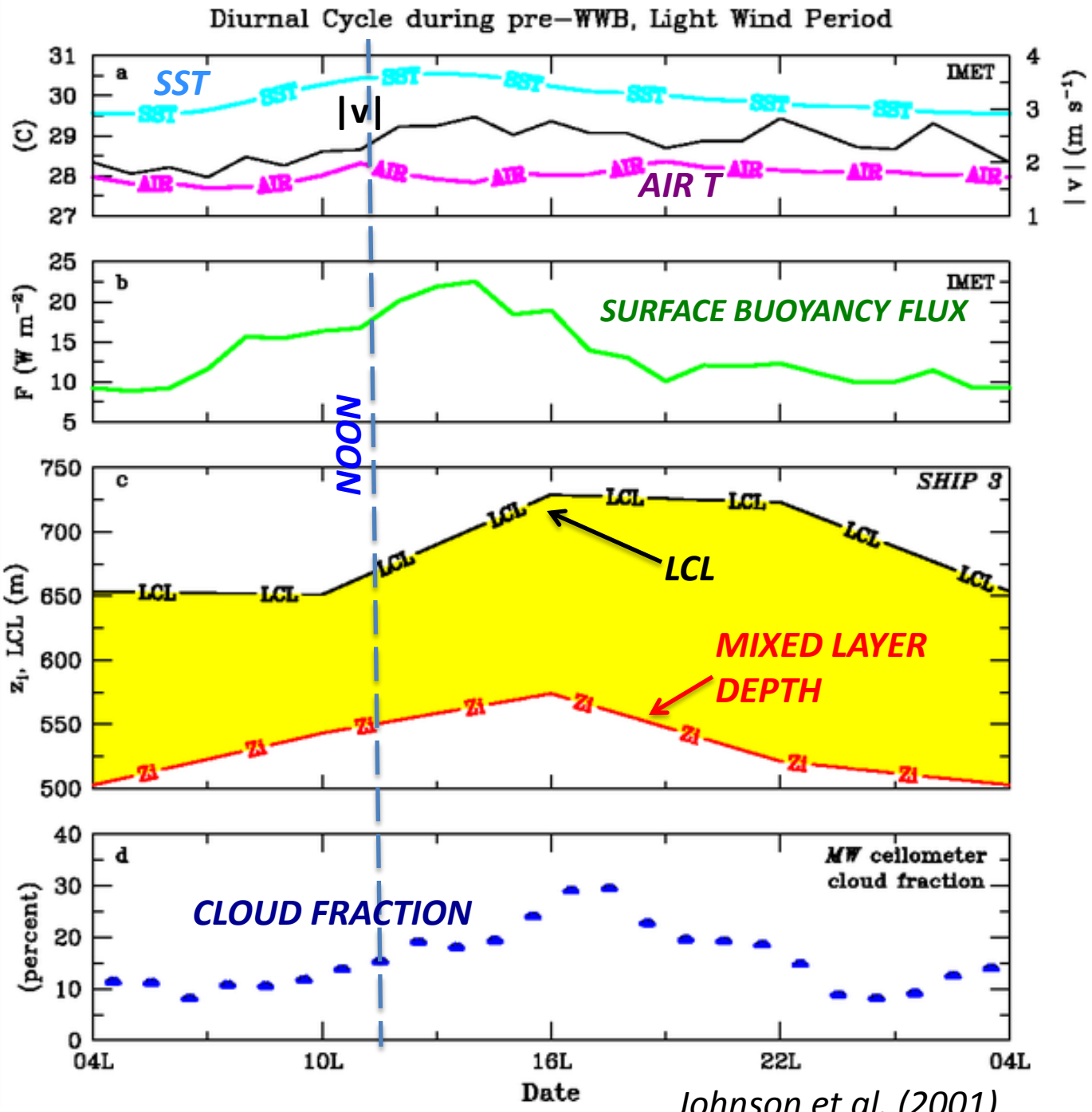
Diurnal cycle is important part of this process and, arguably, enhancement of cloud growth by mesoscale circulations

Large amplitude diurnal cycle – SST, sensible and latent heat fluxes – on light wind days



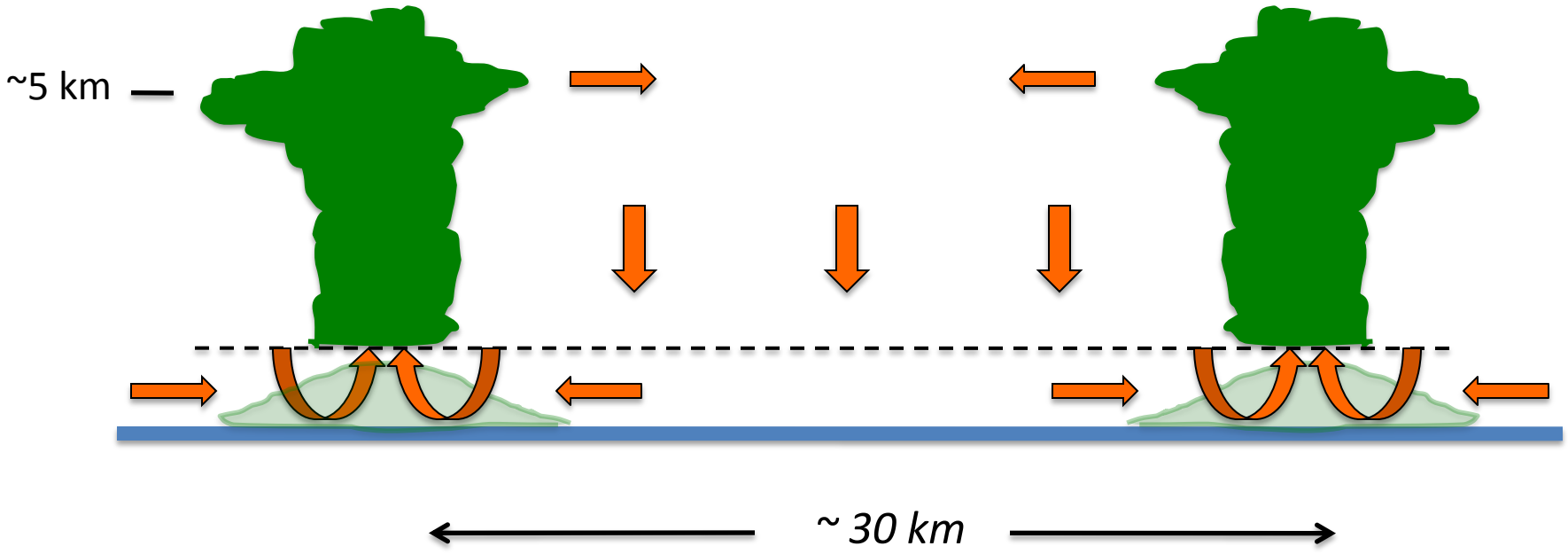
Fairall et al. (1996) bulk flux algorithm, includes low-wind gustiness

- *SST peak near noon, buoyancy flux peak early afternoon*
- *As LCL – z_i decreases, cloud fraction (CF) increases, peaking in late afternoon (more ML eddies reach LCL)*
- *Dry air entrainment into ML decreases CF during evening*
- *Weak secondary CF peak in early morning*



Johnson et al. (2001)

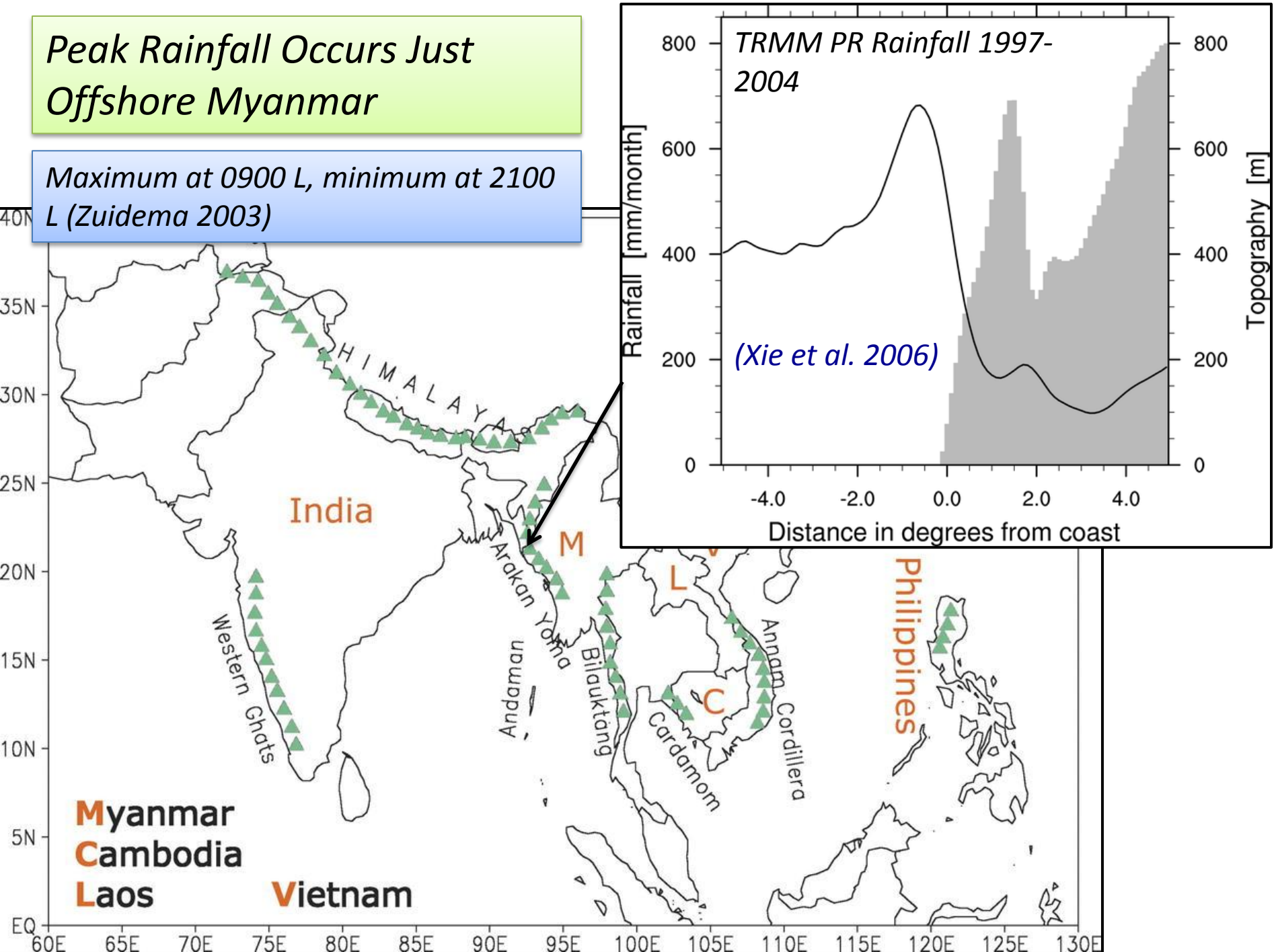
Open Cells

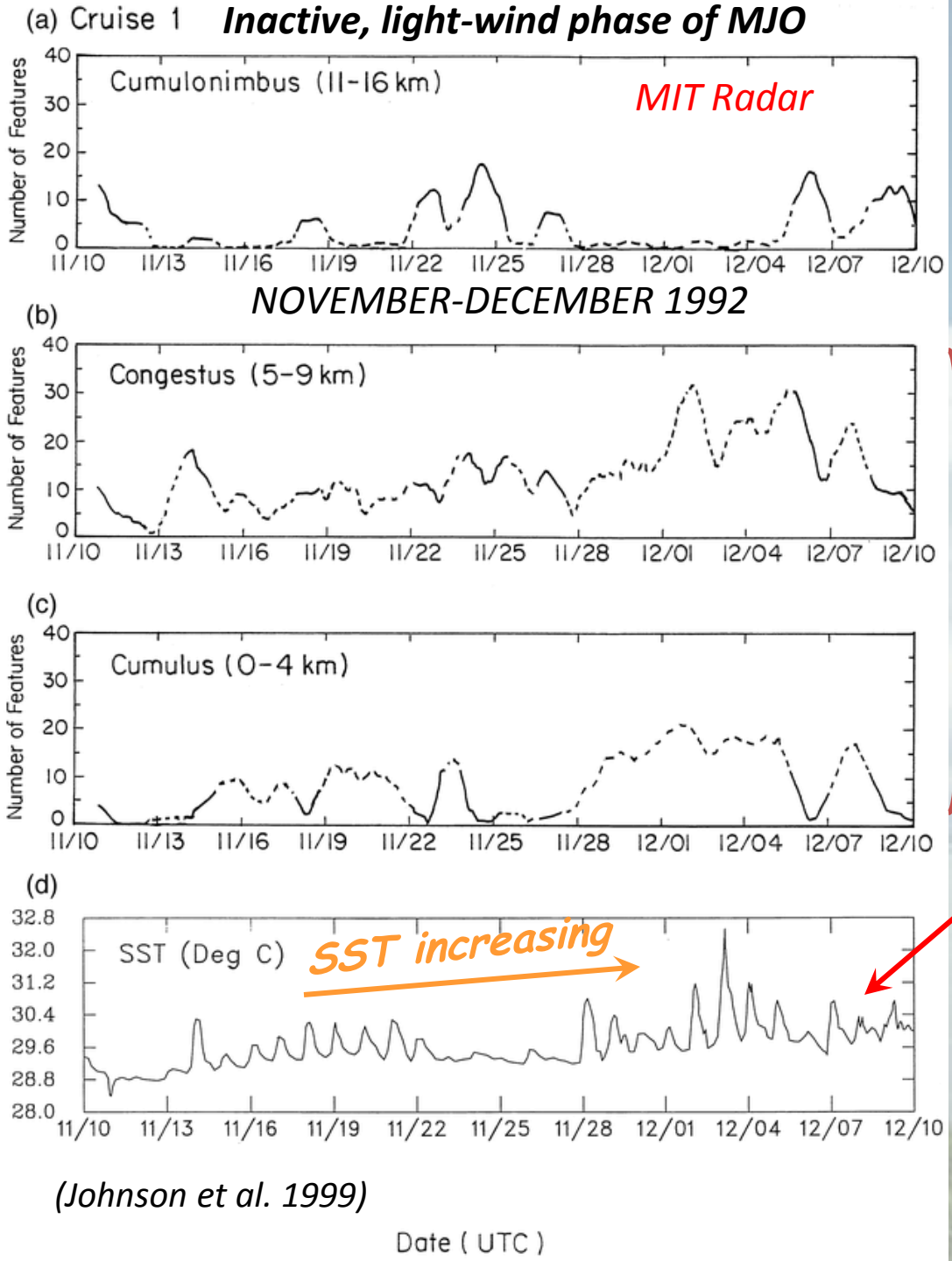


Hypothesis: Mesoscale circulations lead to localized areas of enhanced boundary layer moistening, cloud growth, lower-tropospheric moistening than would otherwise occur

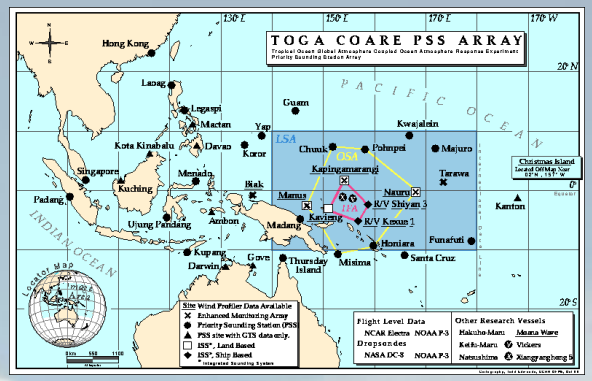
Peak Rainfall Occurs Just Offshore Myanmar

Maximum at 0900 L, minimum at 2100 L (Zuidema 2003)





(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