Investigating the Tropical Coastal Convection Systems Using Cloud Resolving Simulations and Satellite Observation

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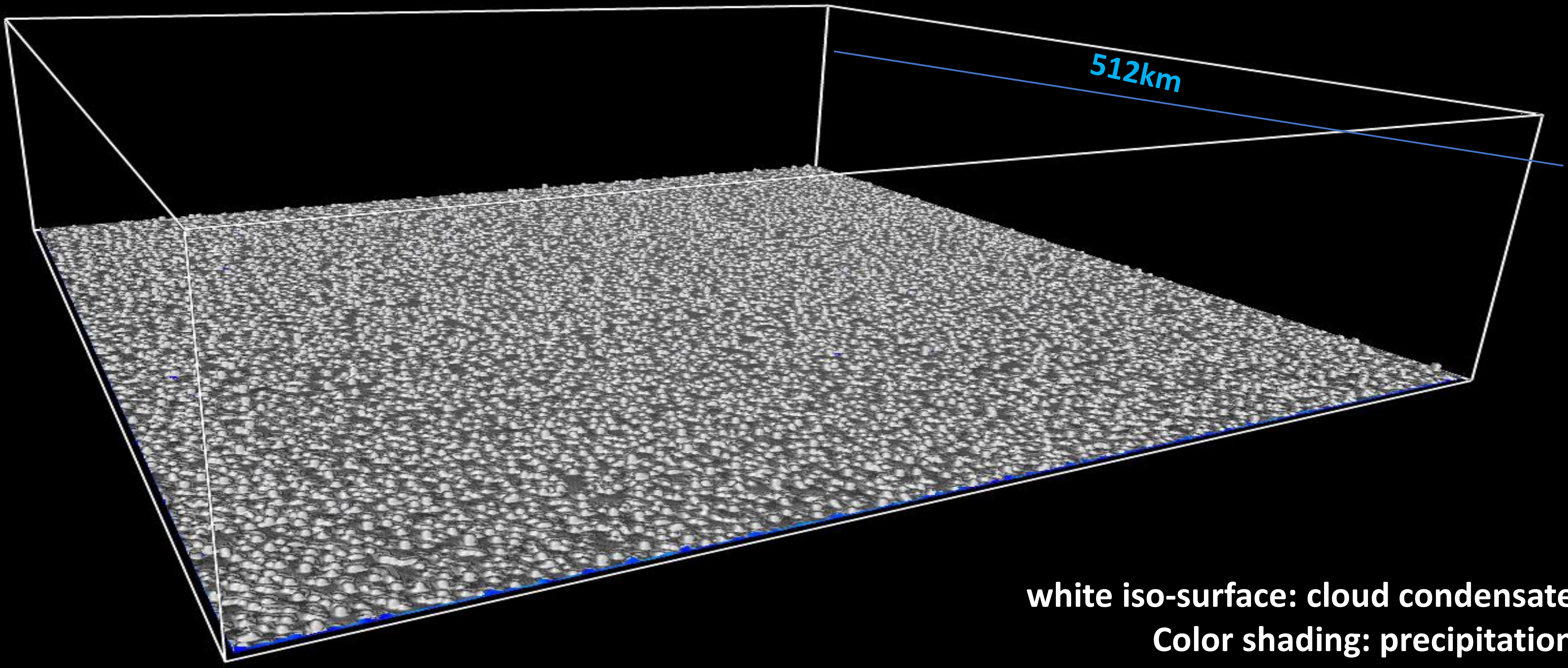
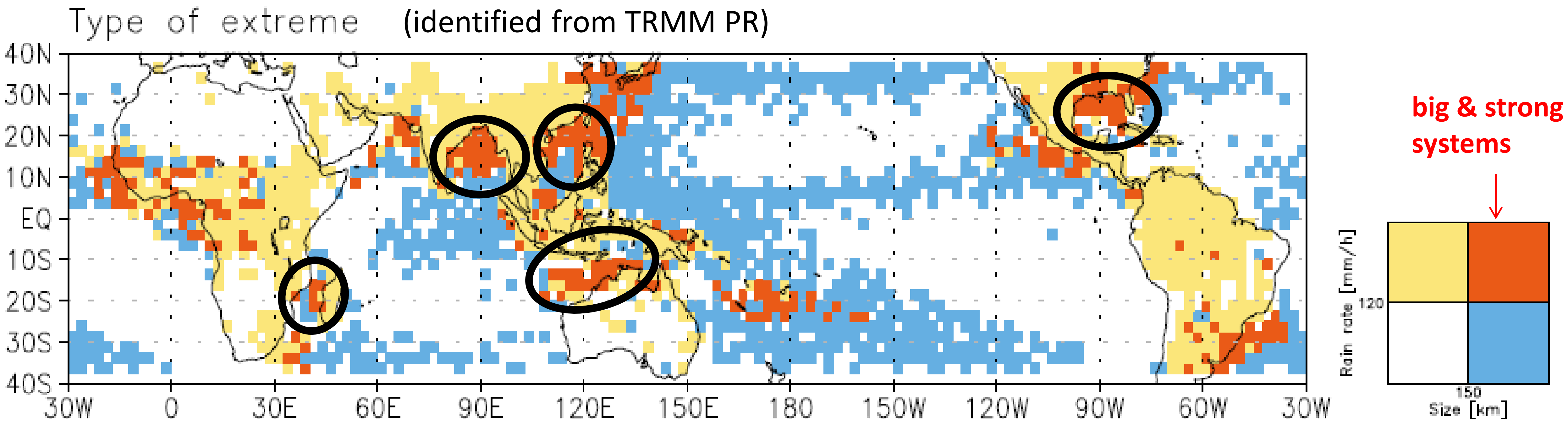
Convection aggregation in radiative convective equilibrium experiments: open ocean

TimeStep: 1 hr



white iso-surface: cloud condensate
Color shading: precipitation

In the Real World: Aggregated Convection Contributes to Extreme Precipitation over Tropical Coastal Oceans



- **[Hamada et al., 2014, J Climate]**: Extreme rainfall over tropical coastal oceans contributed by **"intense and extensive" systems**; likely associated with tropical cyclones (<60%) and convective systems associated with the establishment of monsoons.
- Coastal circulations, generated by land-sea thermal contrast and orography, control the initiation and organization of convection systems
- Often exhibits strong diurnal cycle; sensitive to large-scale condition

Coastal convection systems are focused in the Year of Maritime Continent (YMC, 2017-2019) campaigns

- YMC Scientific Theme 1 – Atmospheric Convection:
- To advance understanding of physical processes governing diurnal, synoptic, intraseasonal and seasonal variability of atmospheric convection and their interaction under the influence of the complex land-sea distribution and topography

Diurnal Cycle of Cloud Cluster (> 100 km^2)

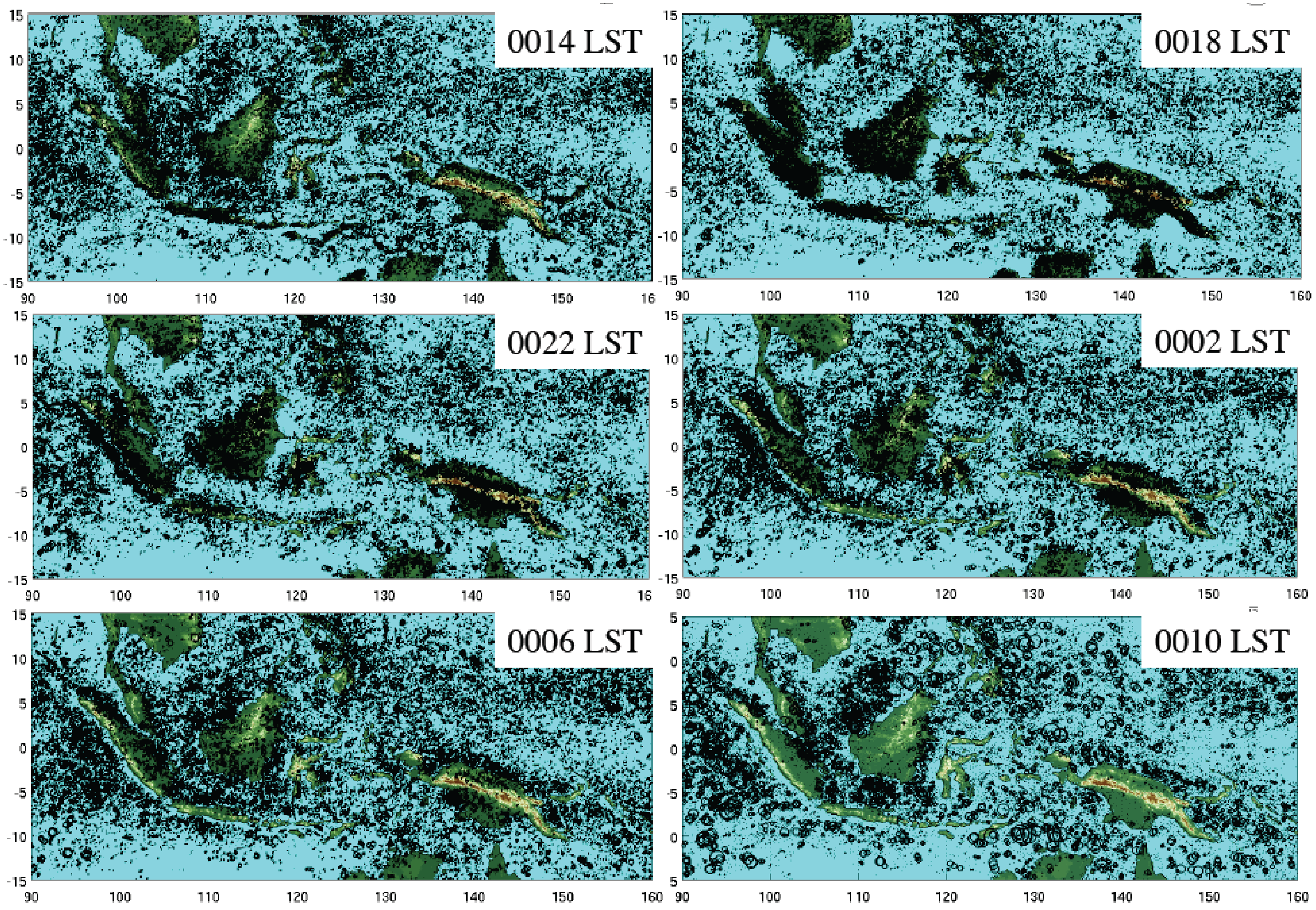


Figure 2.2 Diurnal cycle of cloud clusters defined as cloud top brightness temperature < 208 K. Sizes of each circle is proportional to the cluster sizes (> 100 km^2). Courtesy of Shuyi Chen and Brandon Kerns.

Convection aggregation in radiative convective equilibrium experiments: coastal areas

- Objective: to understand convection aggregation under the forcing of ocean-land-orography configuration
  - With solar forcing to generate diurnal cycle
  - Sensitivity to background wind shear

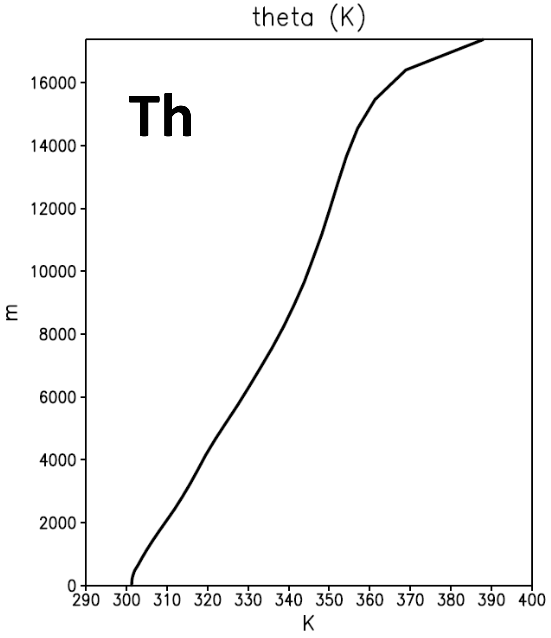
Model and experimental set up

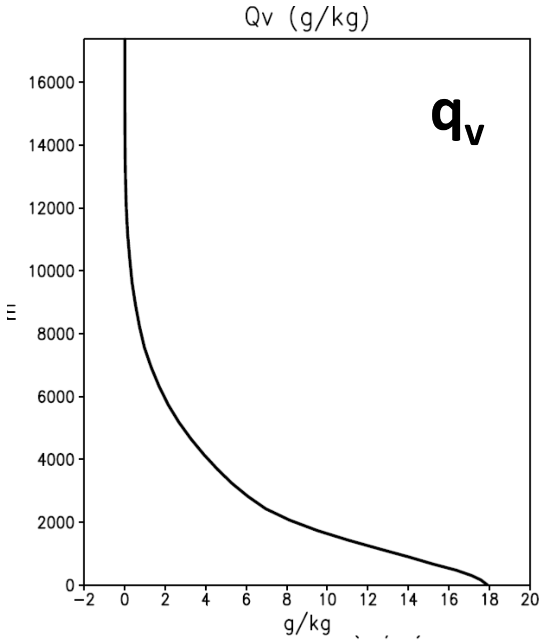
3D cloud-resolving model VVM

(Jung and Arakawa 2008, Wu and Arakawa 2011, Chien and Wu 2016)

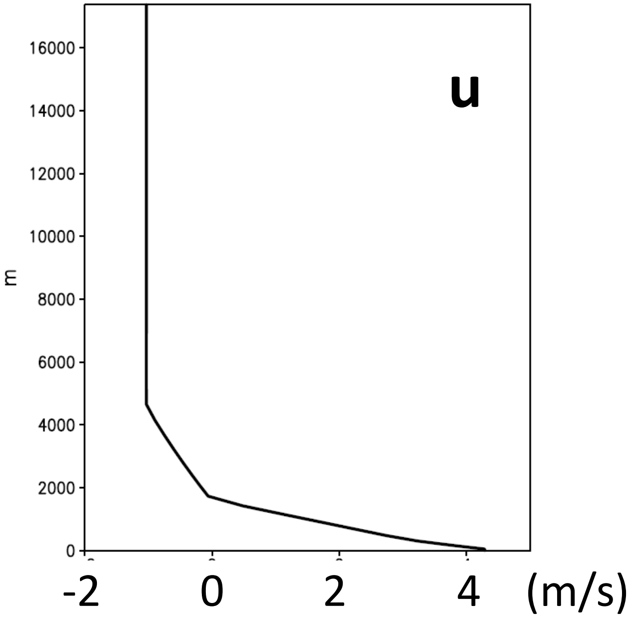
Model	Vector vorticity model (VVM)
Horizontal grid / Resolution	512 x 256 / 2 km
Vertical grid	45 layers with stretched grid (Model top at 30km)
Simulation time	10 days
Time step	10 secs
Microphysics parameterization	Krueger et al. (1995)
Radiation parameterization	RRTMG (Iacono,2008)
Boundary condition	Double periodic with fixed SST (302K) and triangle shaped 1km mountain (128 km) and flat land with evergreen leaf (128km).

Initial Profiles



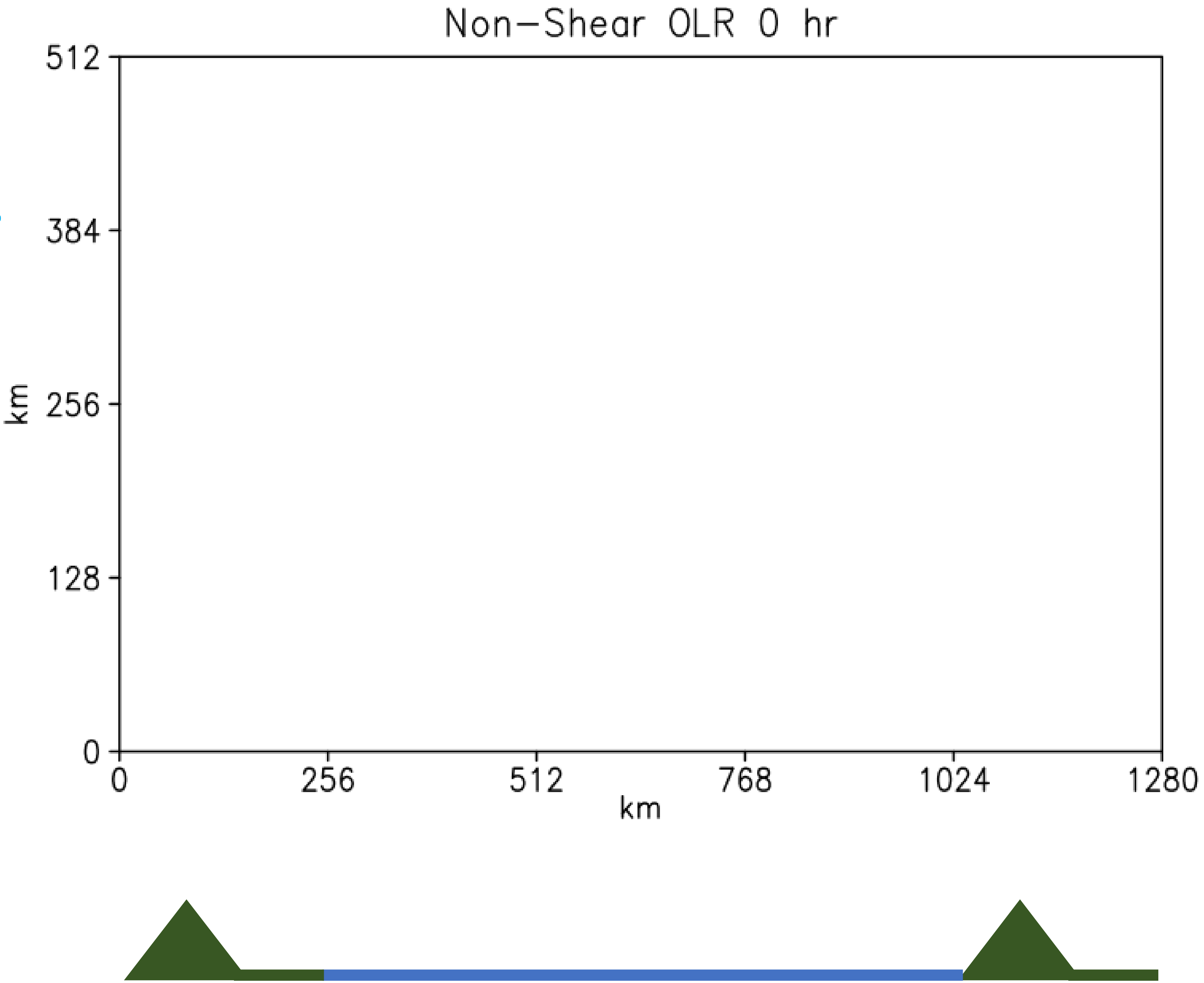


Shear imposed only in the SHEAR simulation



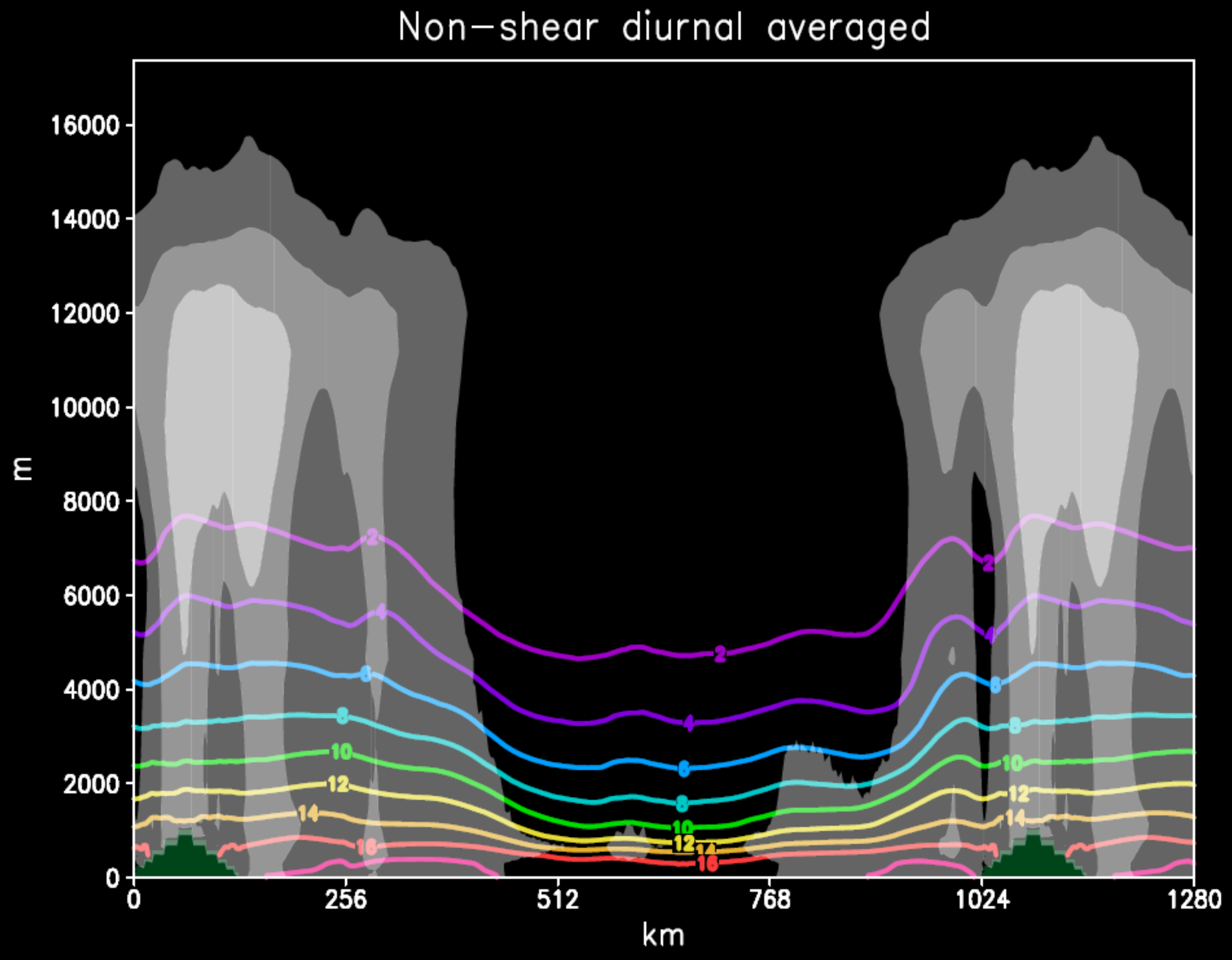
CRM simulation (1): ocean + land with mountain + no shear

(10-day evolution of OLR)

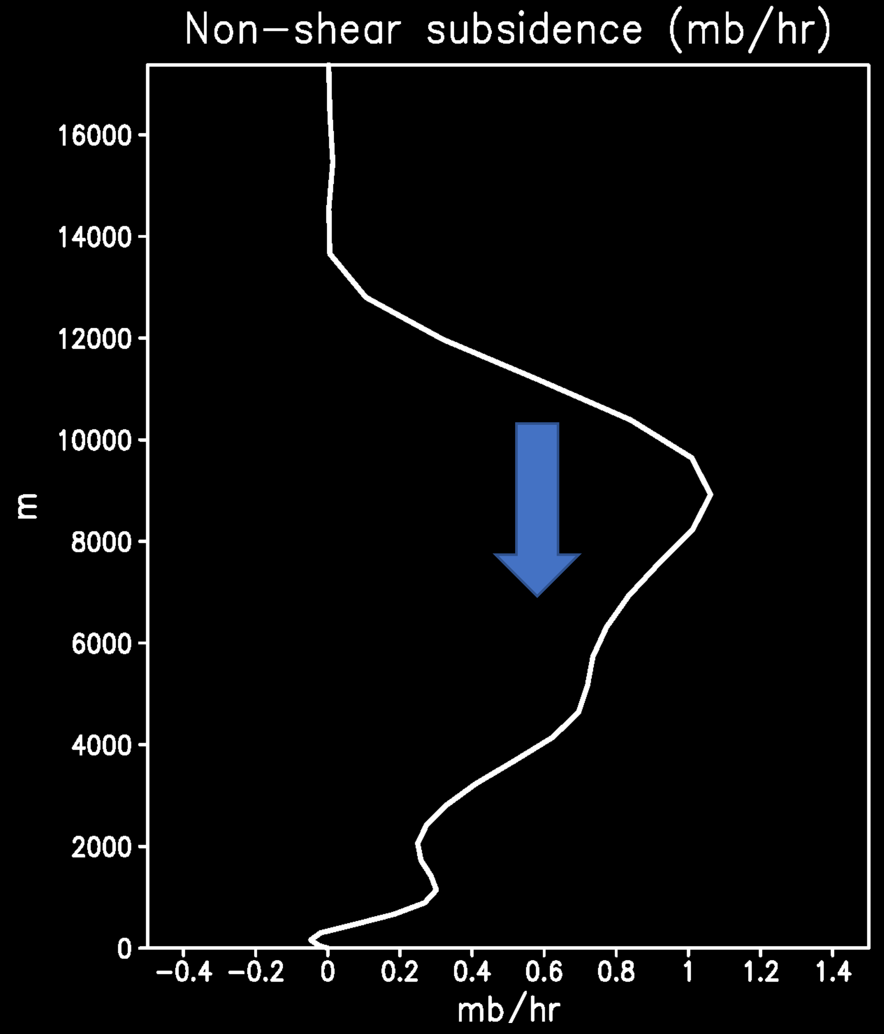


CRM simulation (1): ocean + land with mountain + no shear

All time average CF (shading) and moisture (contour)



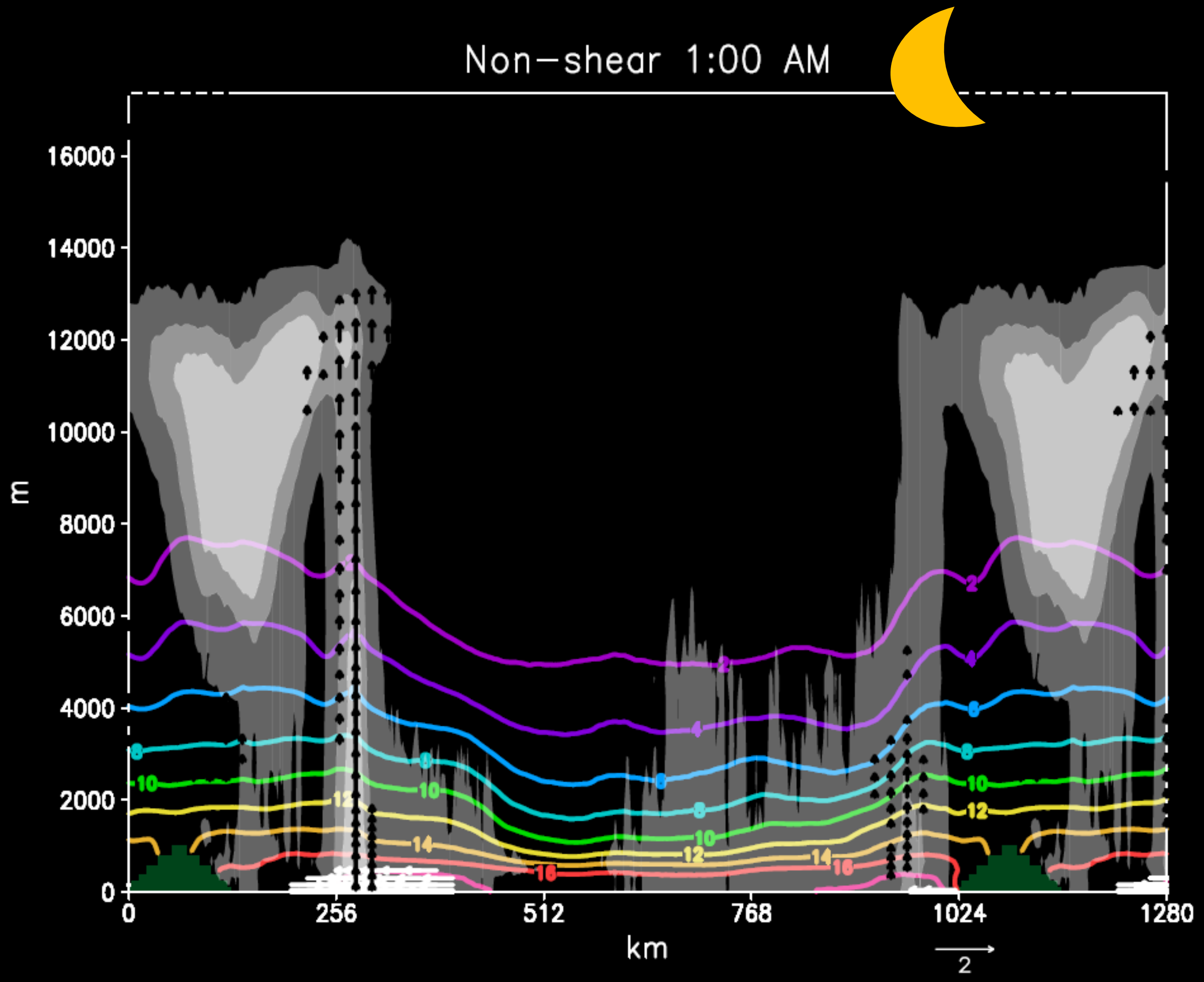
over open ocean

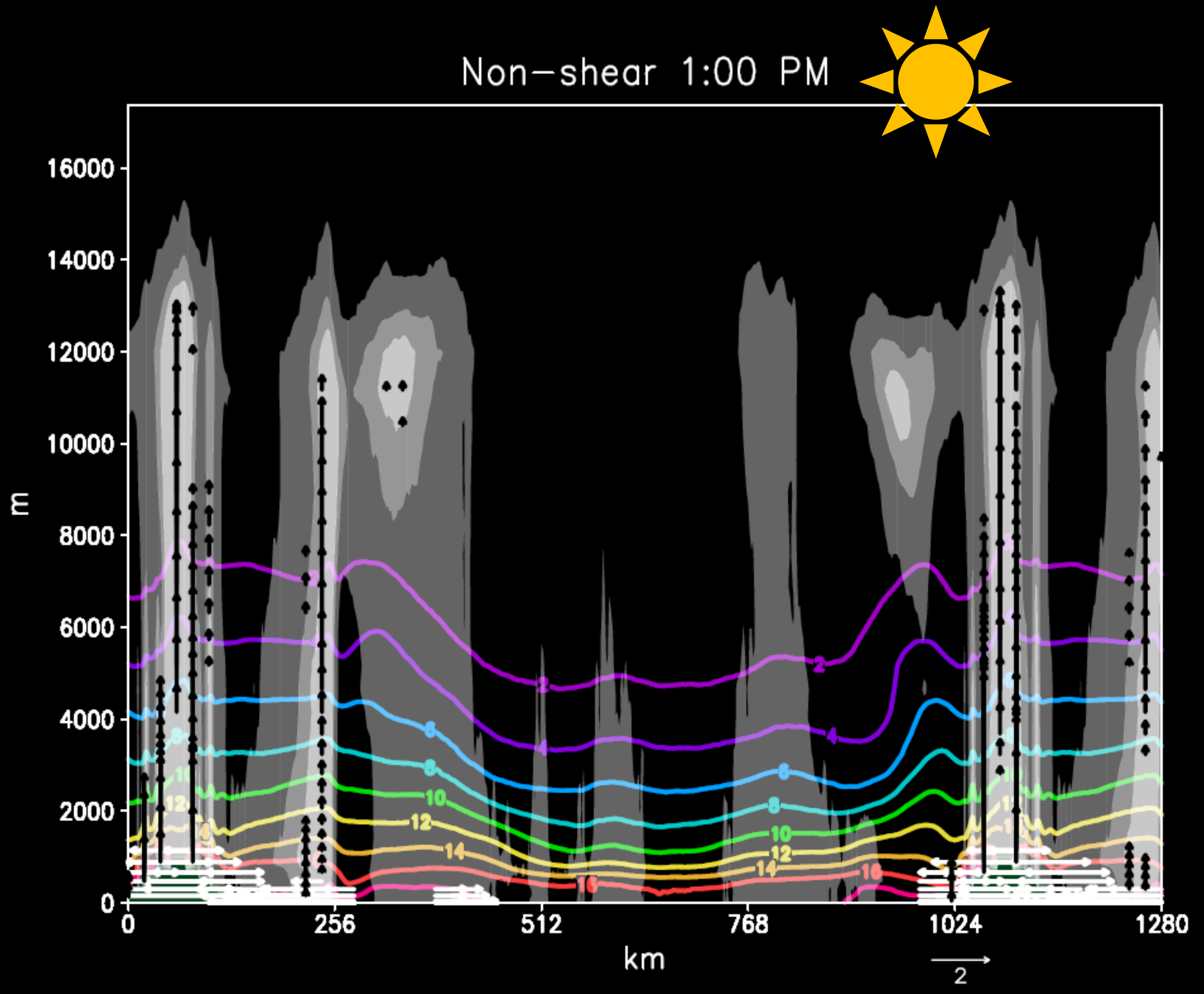


- Strong land-ocean gradient of cloud fraction and moisture
- Dry and strong subsidence over open ocean; convection over land and near-coastal areas
- Local circulation built up by ocean-land configuration

CRM simulation (1): ocean + land with mountain + no shear

CF (shading); moisture (contour); u below 1000 m (white arrows); w > 1 m/s (black arrows)





At midnight:

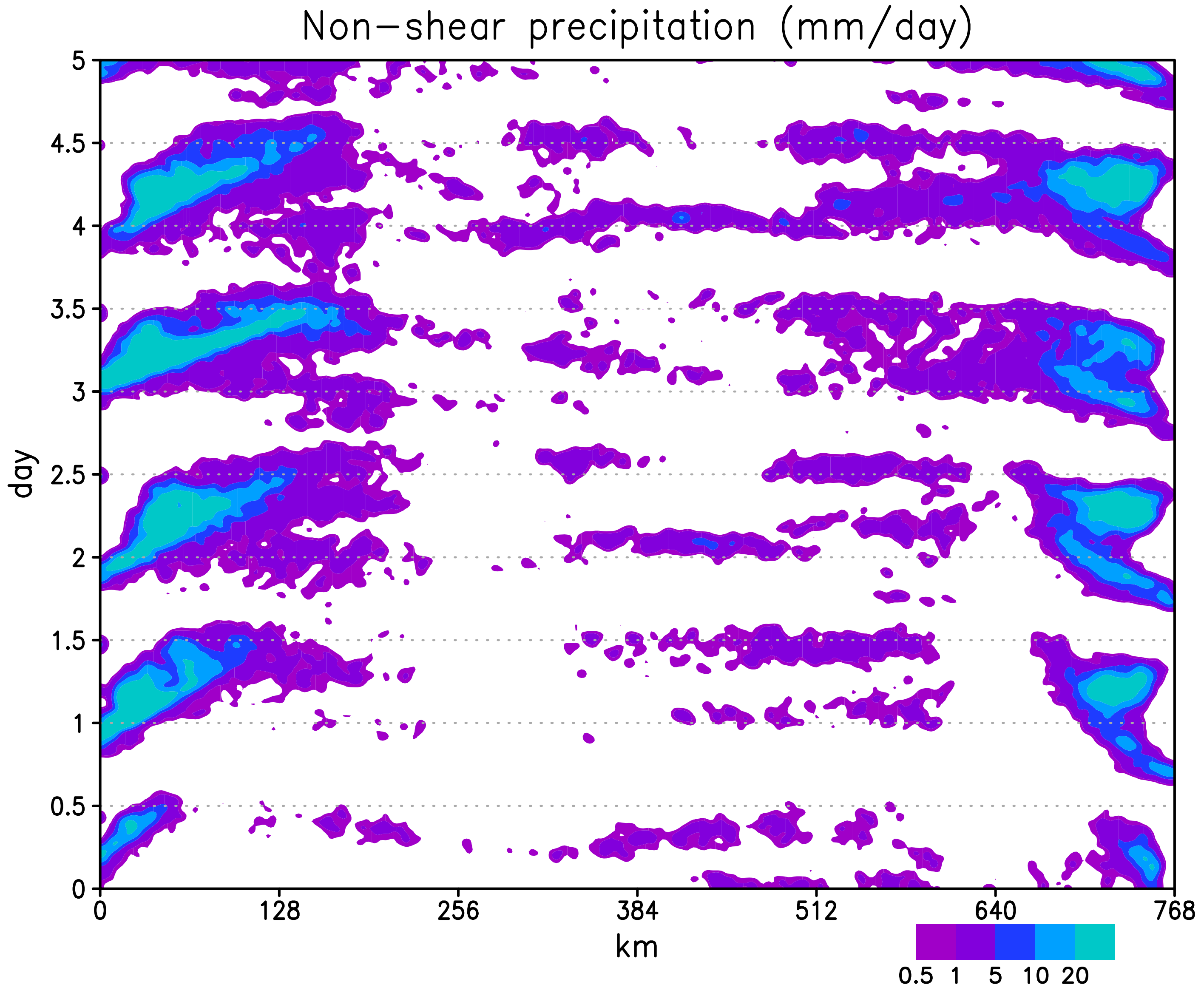
- Coastal systems initiate
- Dissipating thick anvil on top of mountains

At noon time

- Land convection initiates
- Dissipating anvil in coastal region

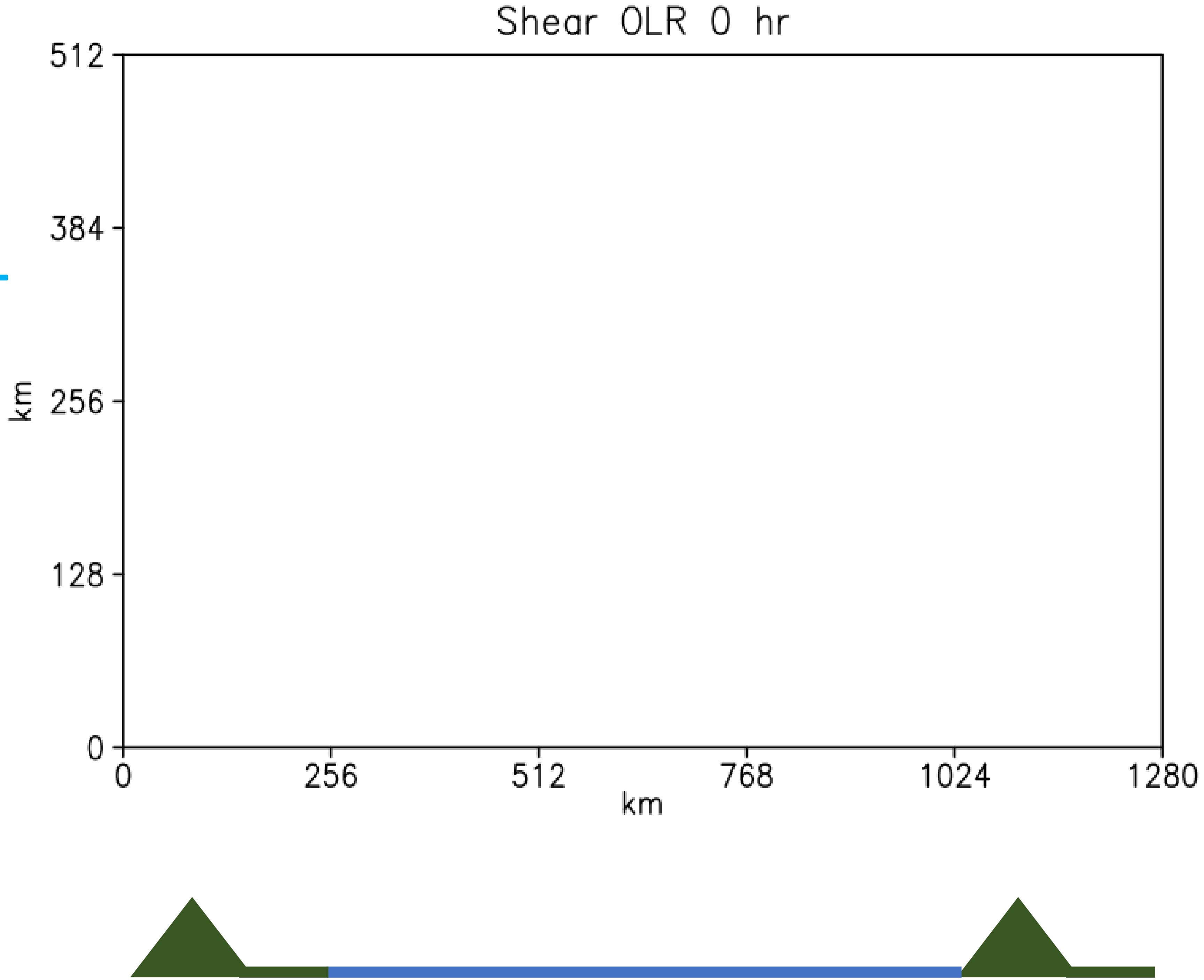
CRM simulation (1): ocean + land with mountain + no shear

- Hovmöller of zonal precipitation <u>over ocean</u>
- Propagation within ~150 km of coast, in a phase speed of ~ 1.5-3.5 m/s

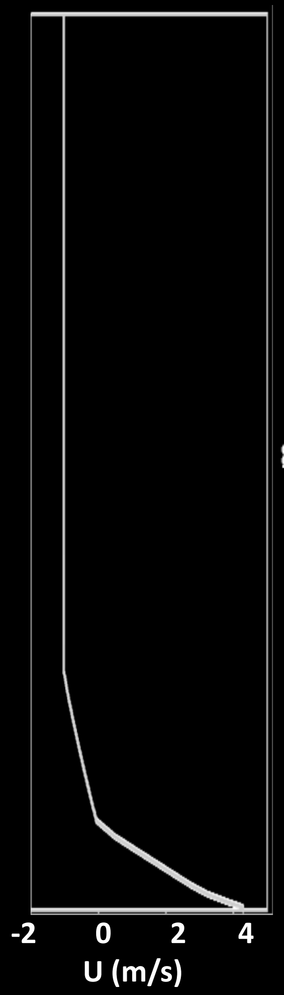


CRM simulation (2): ocean + land with mountain + vertical shear

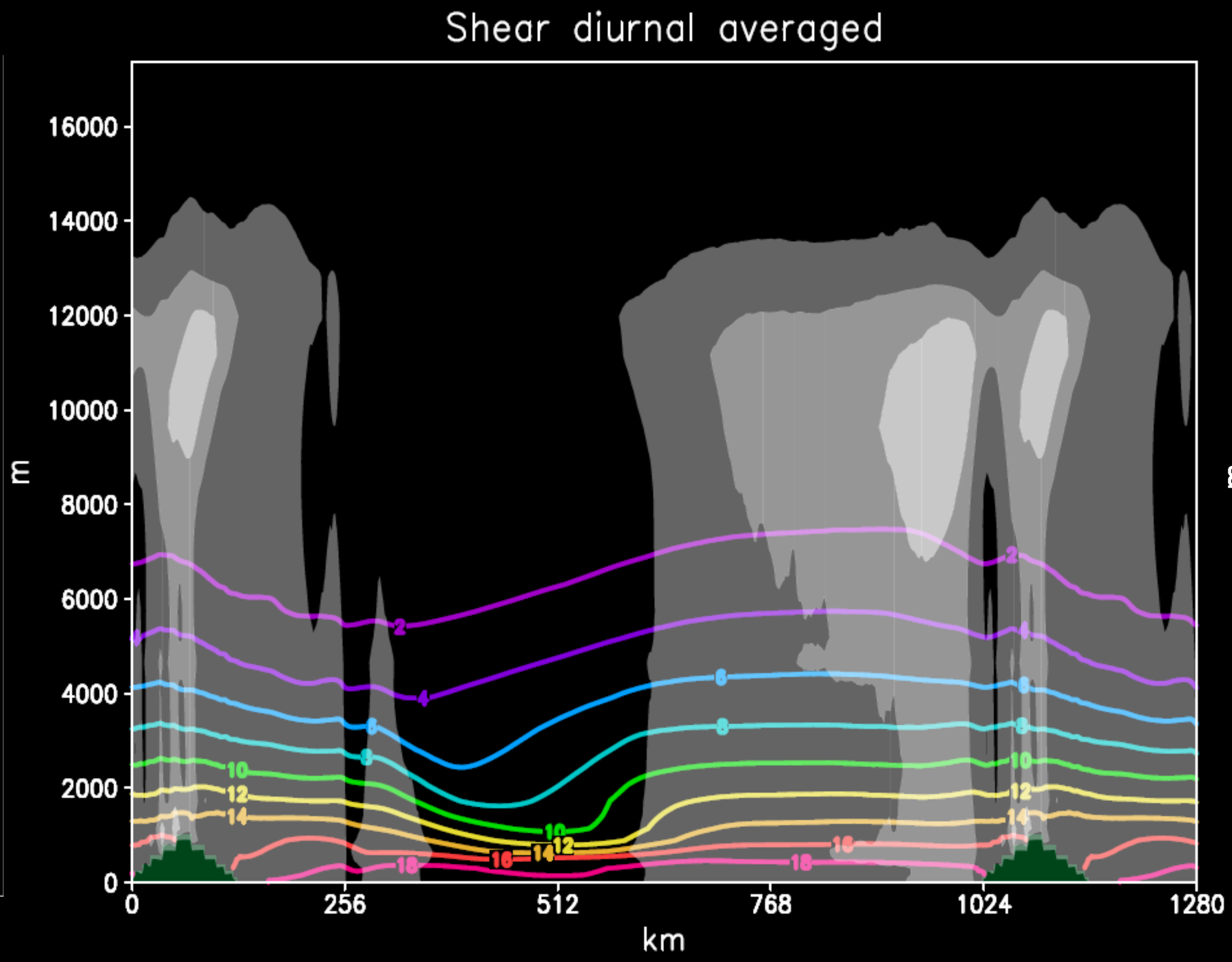
(10-day evolution of OLR)



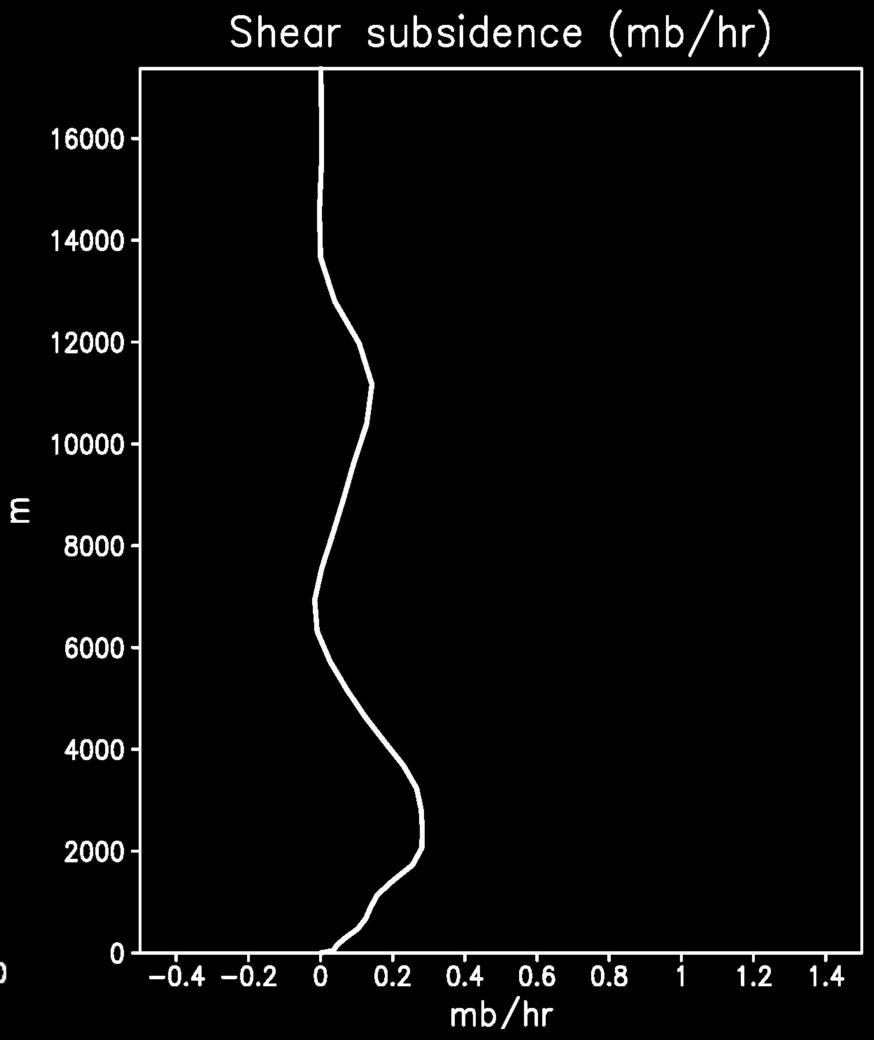
CRM simulation (2): ocean + land with mountain + vertical shear



All time average CF (shading) and moisture (contour)



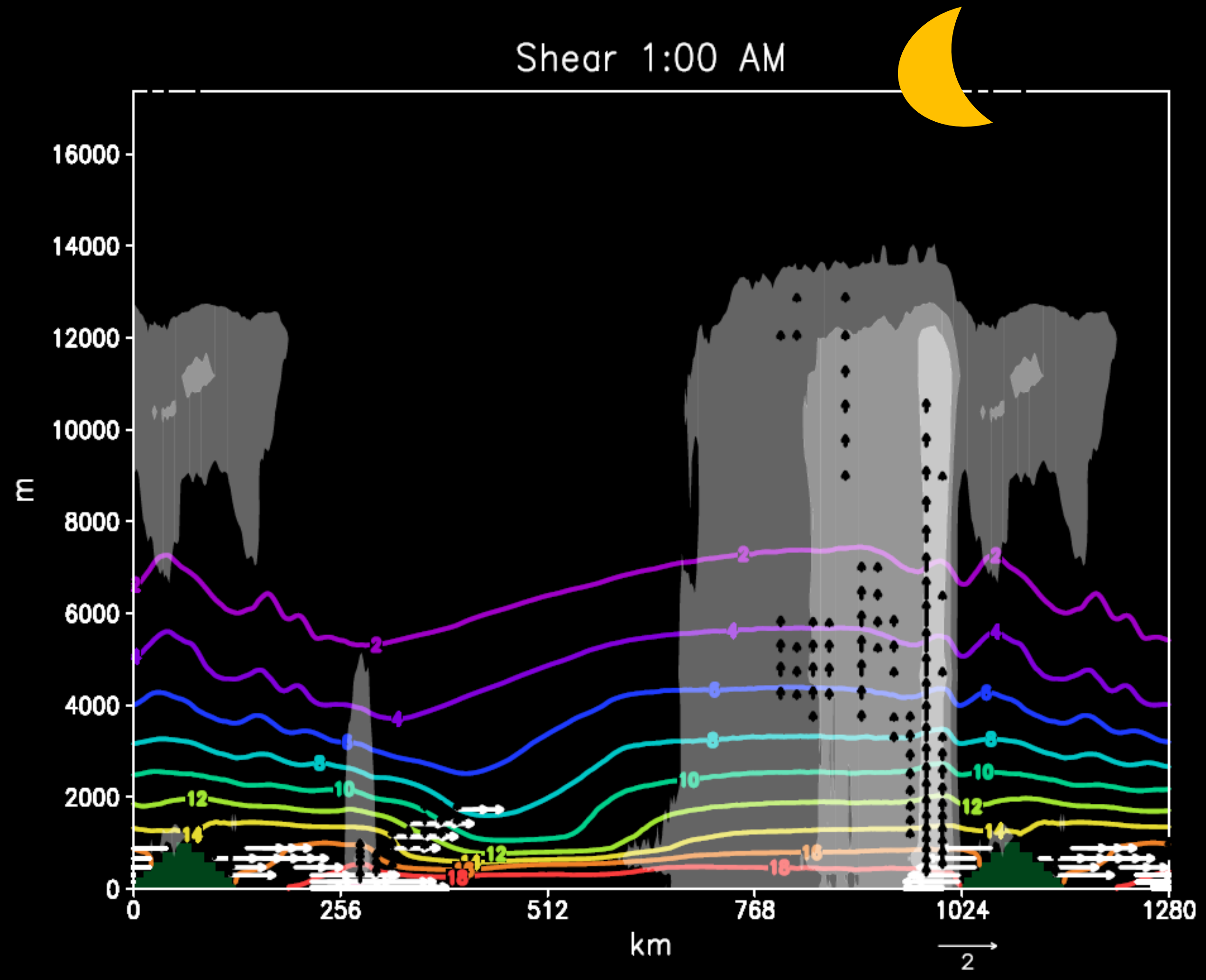
over open ocean

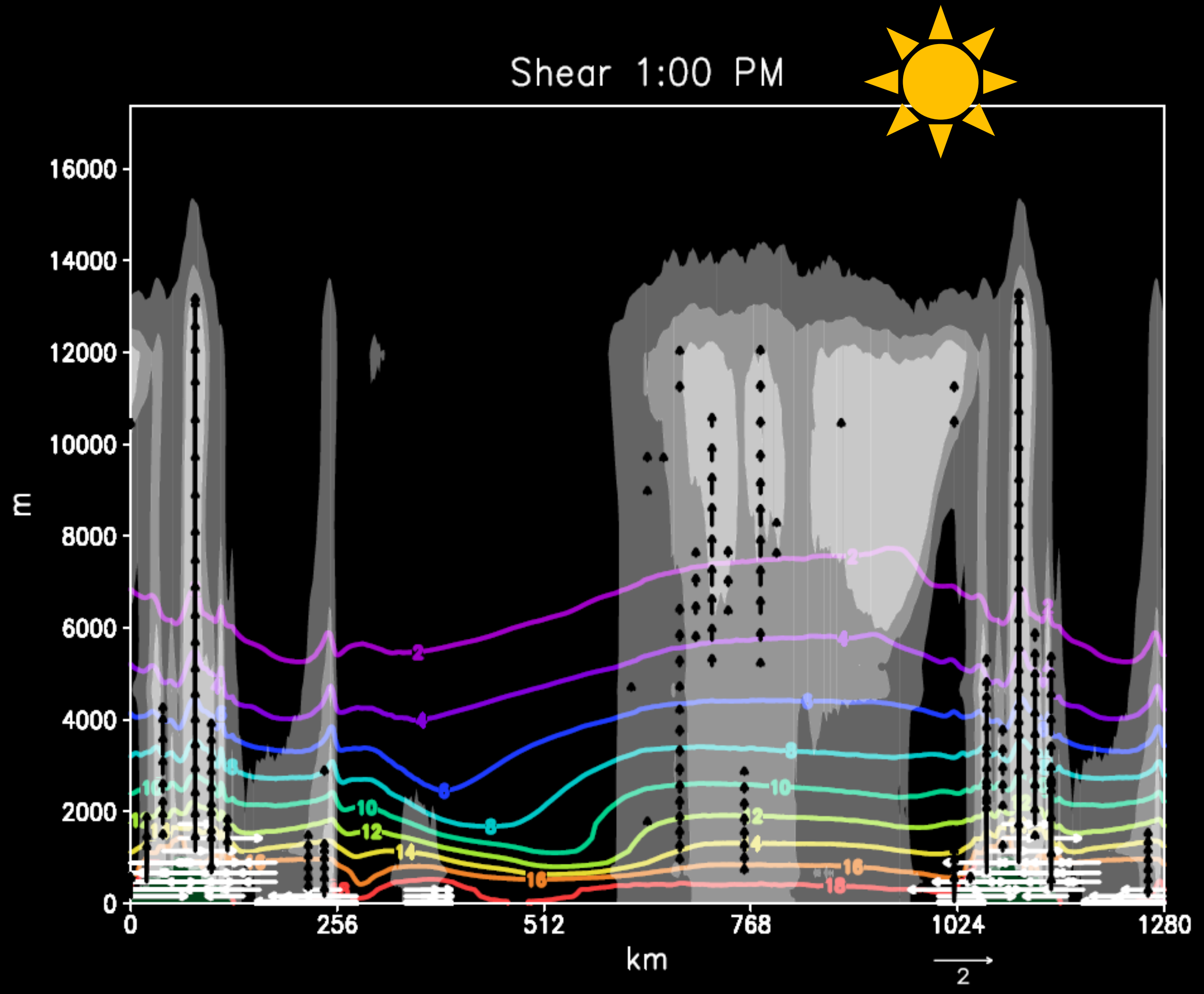


- Convection over land, organized convection over windward coast and propagates to open ocean
- Moisture mode instability over ocean associated with coastal organized convection

CRM simulation (2): ocean + land with mountain + vertical shear

CF (shading); moisture (contour); u below 1000 m (white arrows); w > 1 m/s (black arrows)





At midnight:

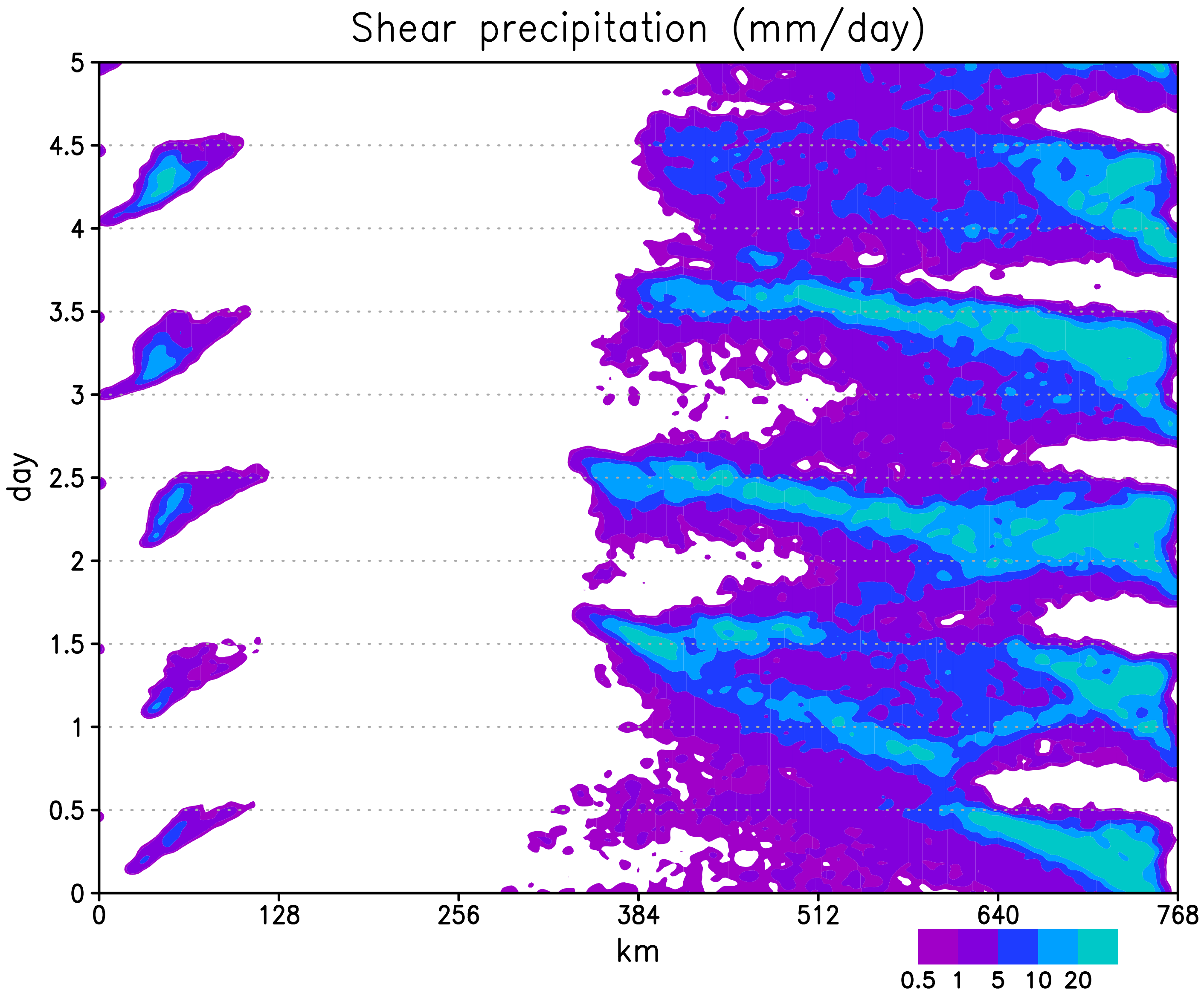
- Coastal systems initiate and organize/propagate
- Dissipating anvil on top of mountains

At noon time

- Land convection initiates
- Dissipating anvil in coastal and ocean region

CRM simulation (2): ocean + land with mountain + vertical shear

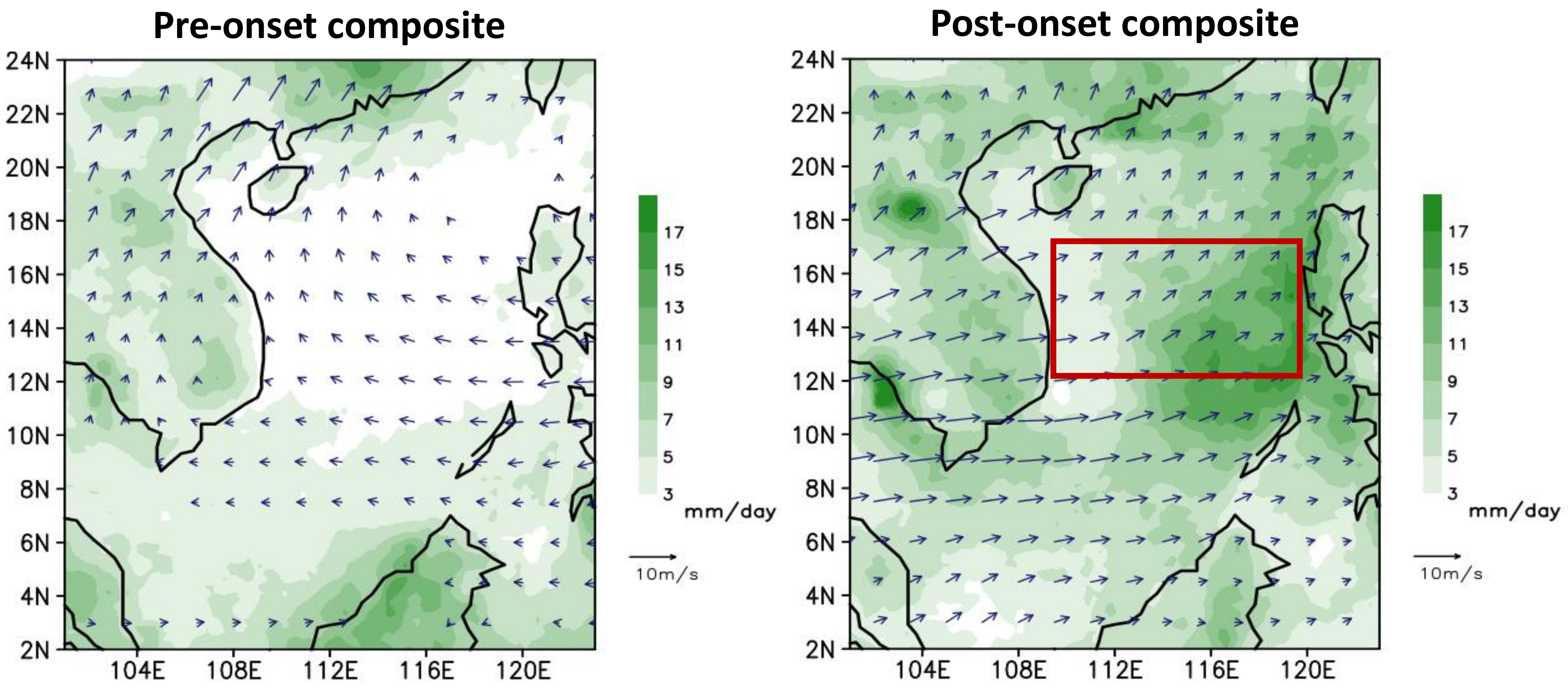
- Hovmöller of zonal precipitation over ocean
- Propagation over more extensive distance (> 350 km) from the windward coast. (phase speed ~ 4-7 m/s) Mechanism?



In the real world: Examples from South China Sea Monsoon Onset

- Quantify the diurnal characteristics of organized convection over South China Sea (SCS) before and after the summer monsoon onset identified from satellite observations
- **TRMM 3B42 Precipitation Rate (1998-2015)**
  - 0.25^o, 3 hourly (00, 03, 06…21 UTC)
- **CloudSat GEOPROF-lidar Cloud mask (2007-2010)**
  - vertical cloud mask based on CloudSat CPR reflectivity and CALIPSO lidar backscatter
  - Δx = 1 km, Δz = 125 m (curtain), twice per day ~1:30pm/1:30am)

Dramatic change in large scale circulation and precipitation within ± 20 days of SCS summer monsoon onset

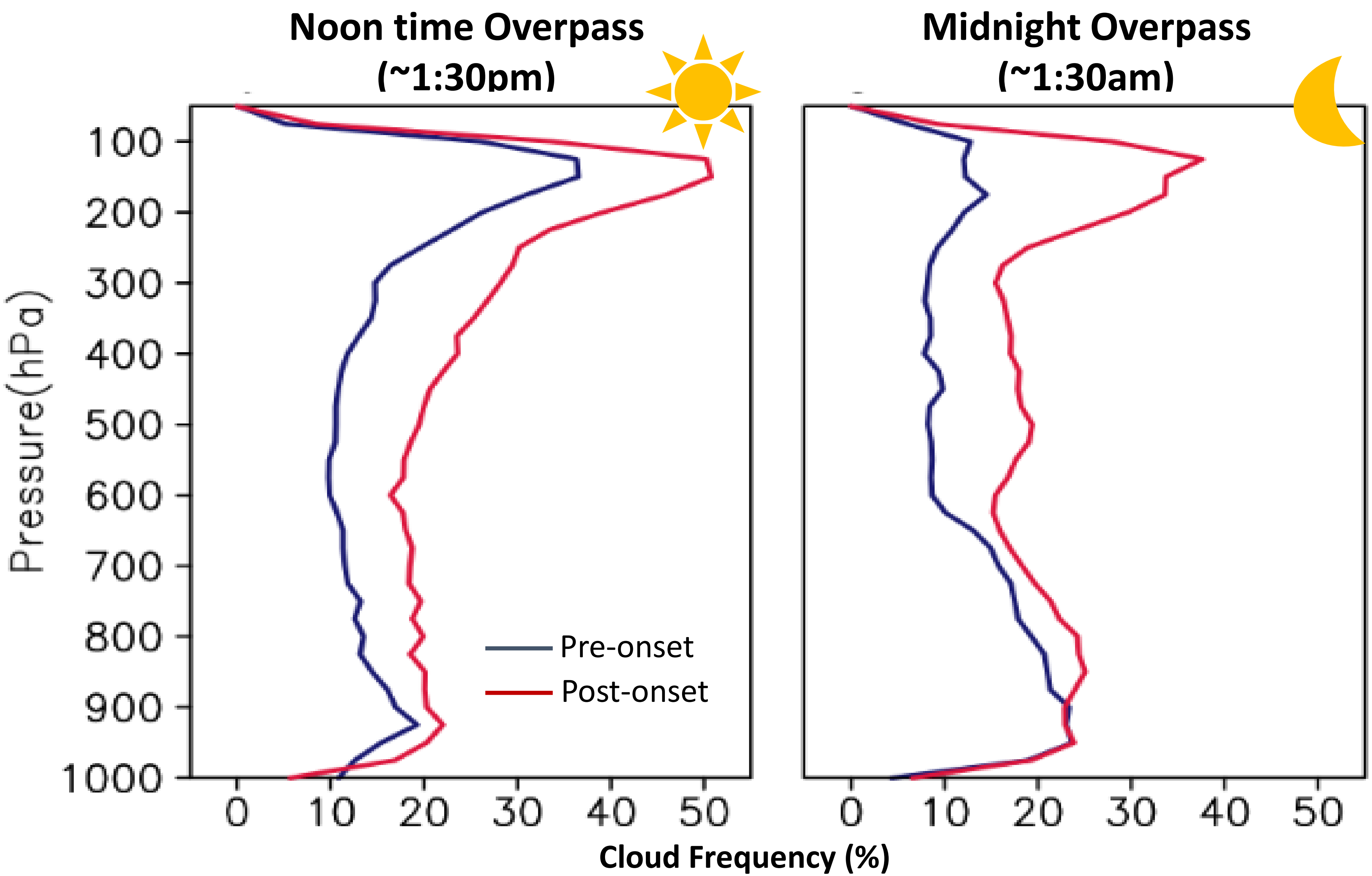


ERA-Int 850hPa wind (vectors) & TRMM 3B42 precipitation (shading), 1998-2015

Composite = average of 20 days before/after the onset date for all 17 years, based on SCSSM U_{850} onset index

Day-night Contrast of Vertical Cloud Frequency over Ocean

- CloudSat GEOPROF-lidar cloud mask (2007-2010)
- Nighttime: Significant increase in mid-level and high cloud (anvil)
- Daytime: increase in all levels
- Radiative-convective instability?

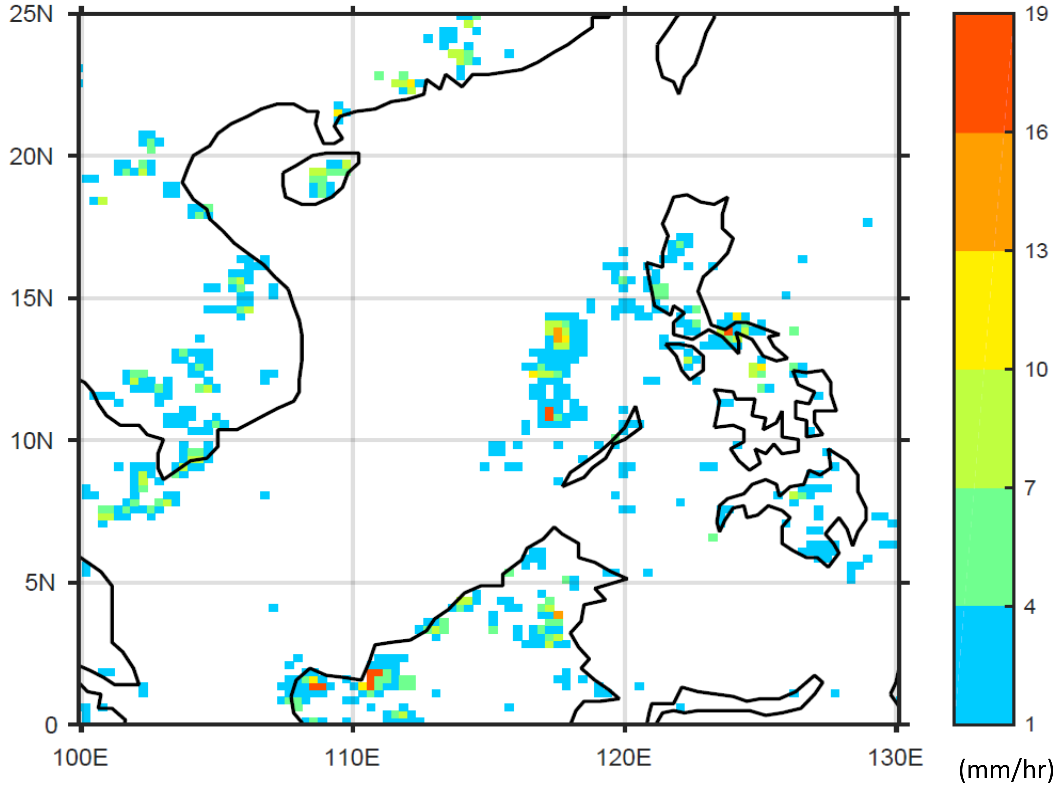


12.5-17.5°N, 110-120°E

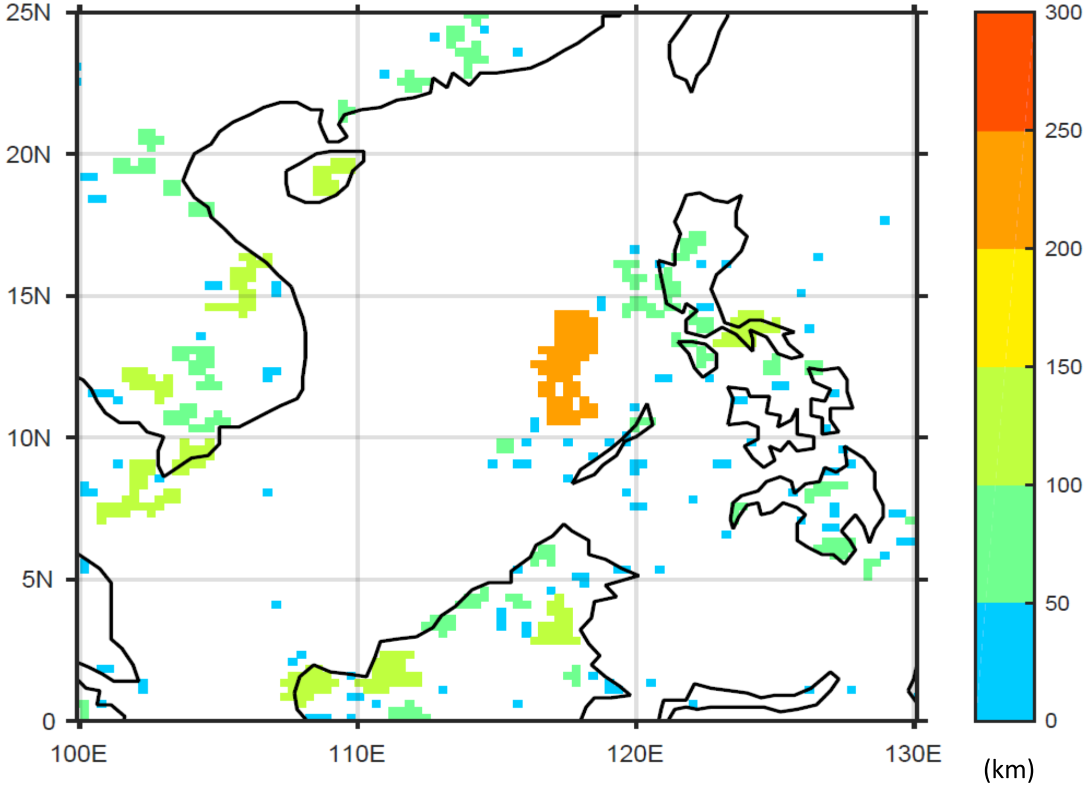
Quantify the size of connected precipitating area

- Identifying contiguous convective precipitation pixels (**> 1 mm/hr**) using four-way connection segmentation method [Wielicki and Welch, 1986; Wielicki and Parker, 1992; Tsai and Wu, 2016]
- The number of connected pixels determines the area of precipitating area
- Horizontal size scale = $\sqrt{Area}$

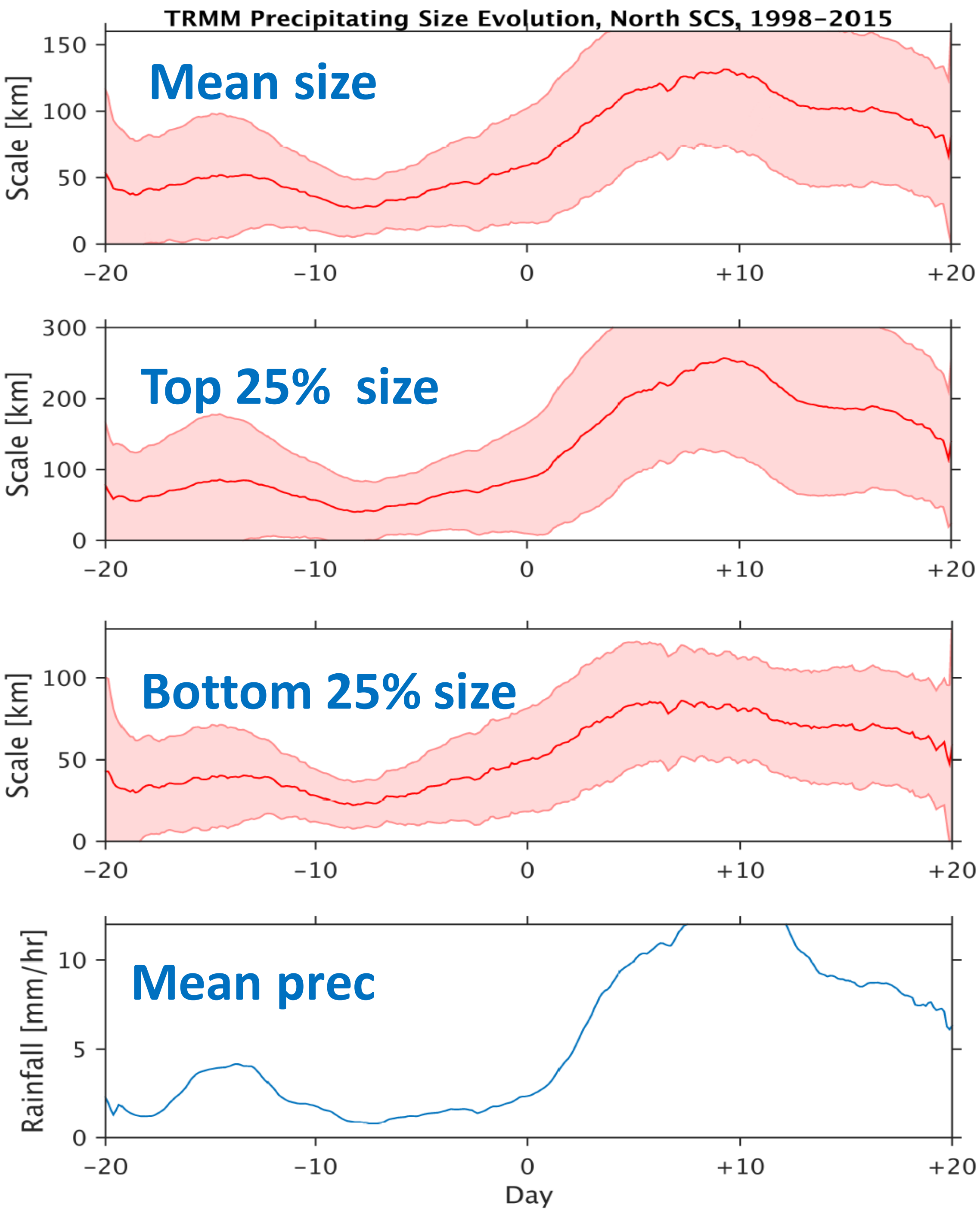
Precipitation rate (> 1 mm/hr)



Horizontal scale of precipitating area



Evolution during onset: sharp increase in precipitation intensity and convective system size



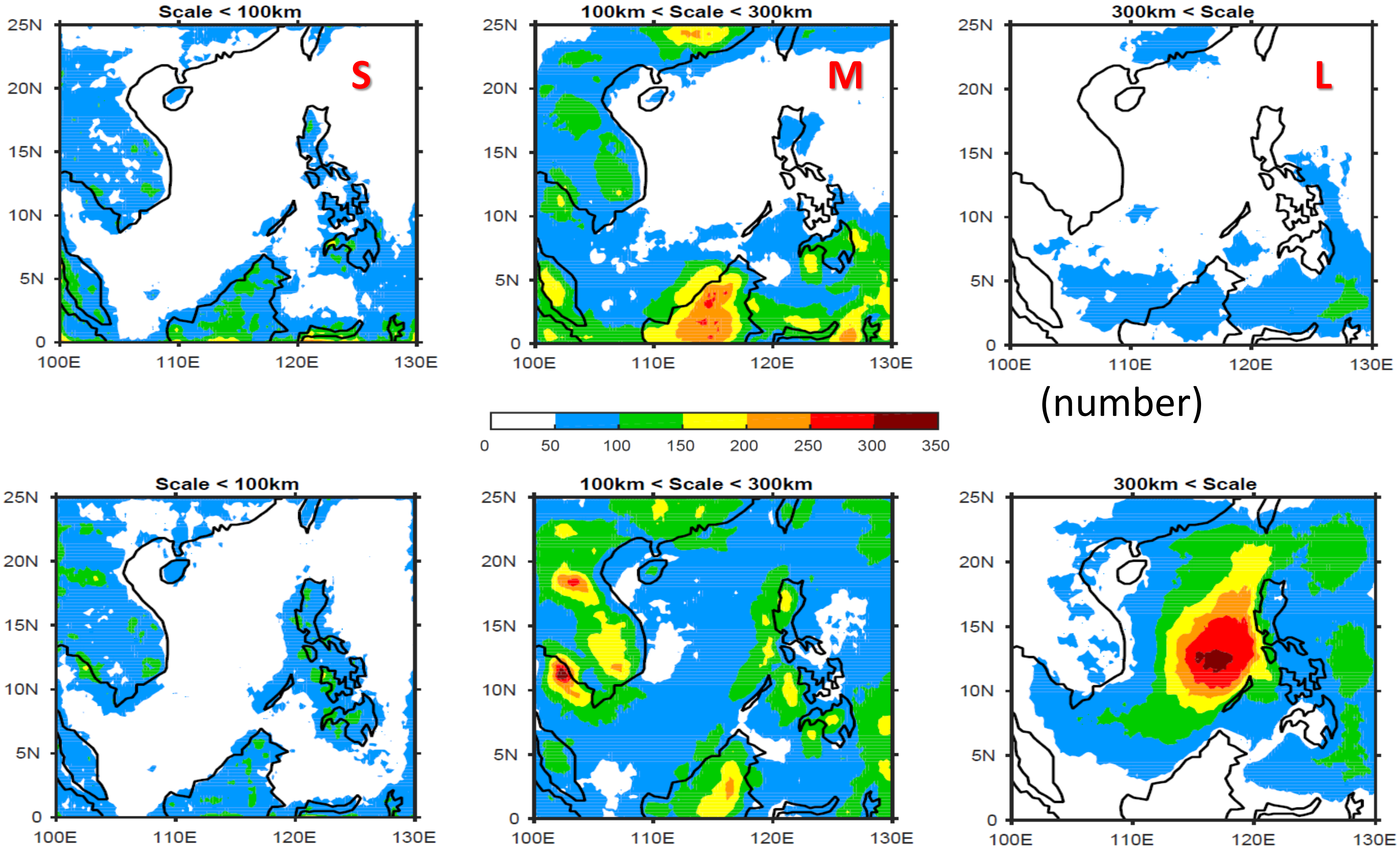
TRMM 1998-2015

Frequency of occurrence by size category: S (<100km), M(100-300km) and L(>300km)

TRMM 1998-2015

Pre-Onset

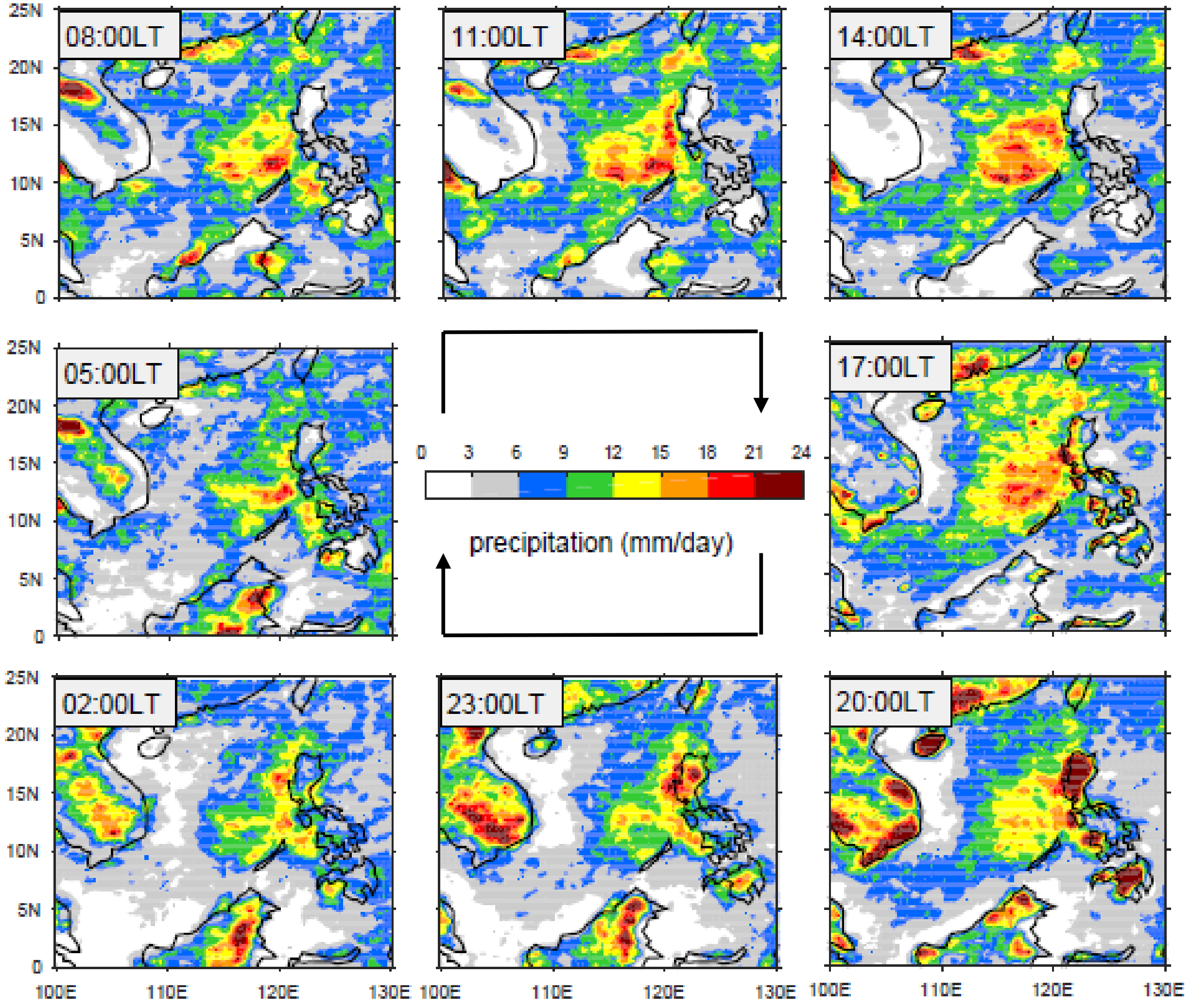
Post-Onset



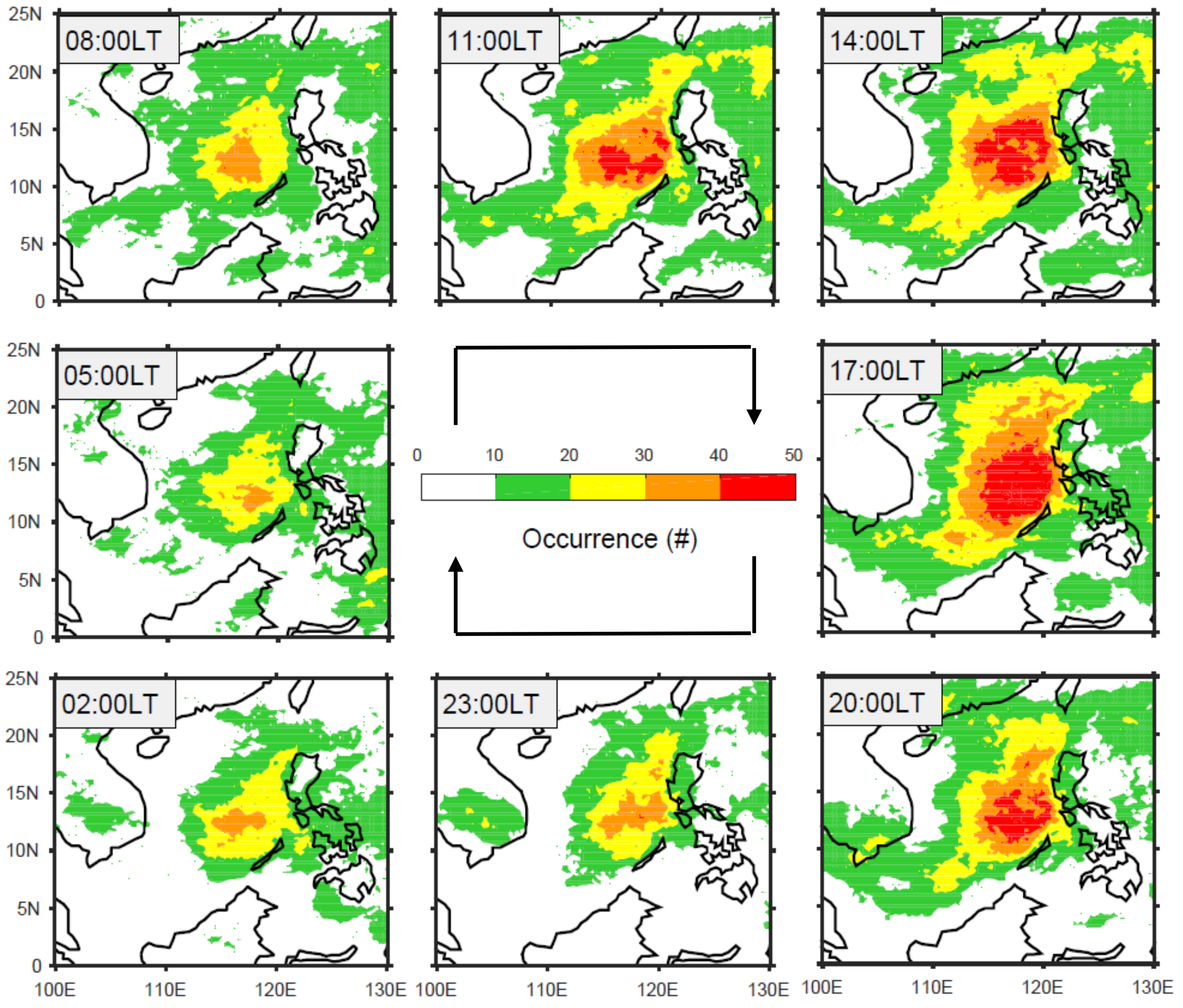
Post-Onset Diurnal cycle

0~+20d composite TRMM 3B42 1998-2015

3-hrly Precipitation



Frequency of L system (> 300 km)

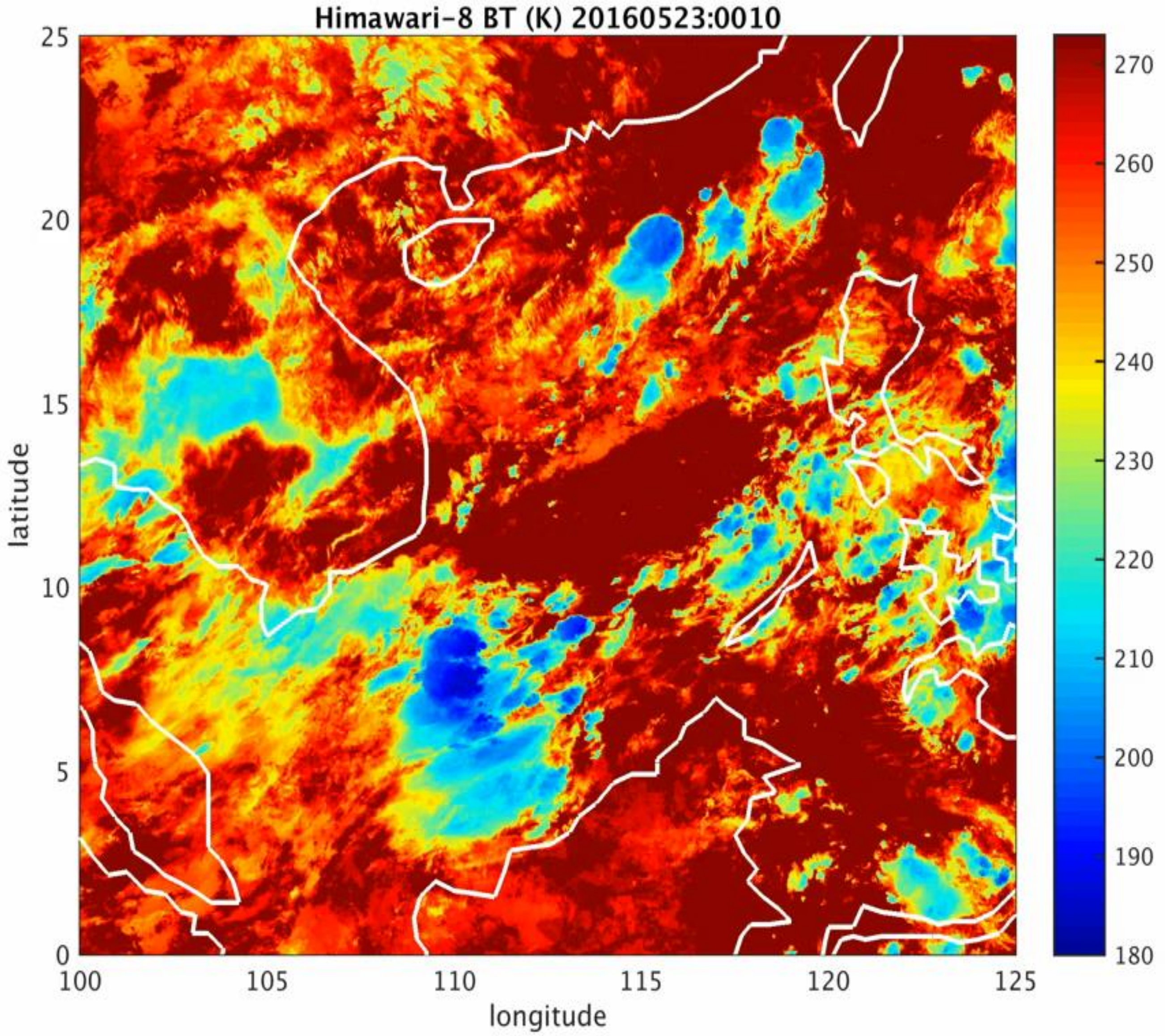


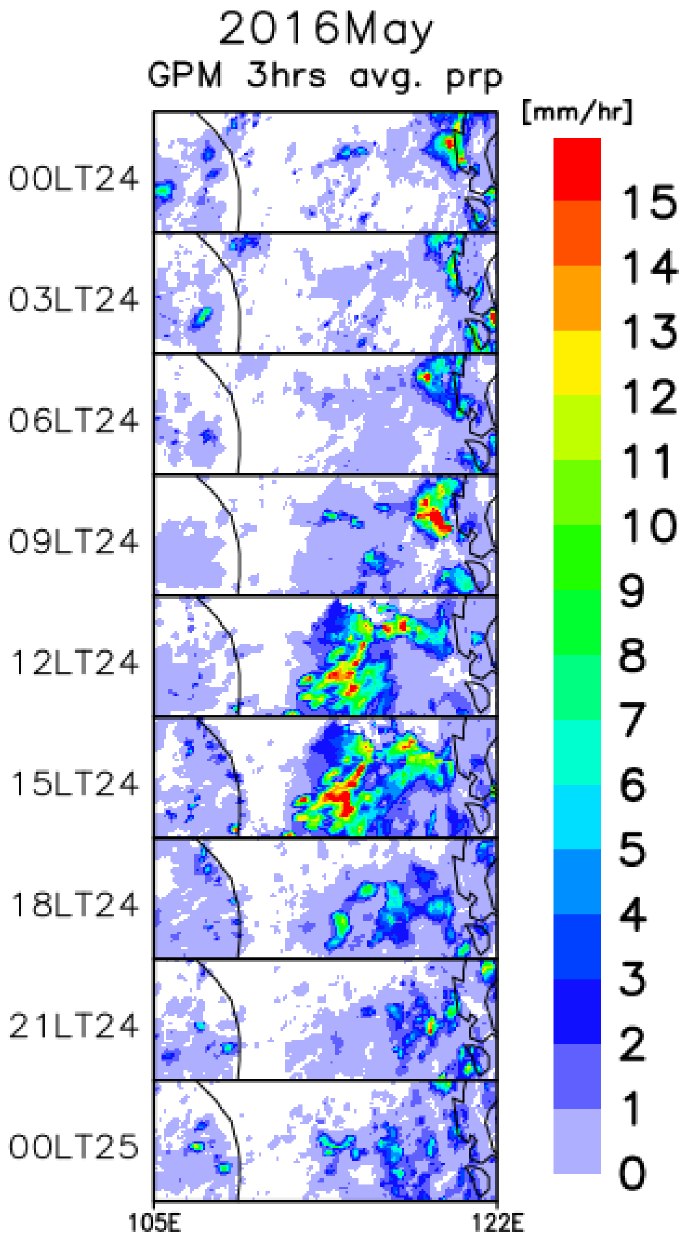
Summary

- Convection organization and diurnal cycle under the influence of land, ocean and topography, and it response to large scale forcing is studied by idealized cloud resolving simulations, and satellite analysis over SCS monsoon onset
- Current results support the YMC hypotheses regarding DC convection:
  - ✓ The contrasts between convection over land and water come mainly from the roles played by the Triggering, Propagation, and Upscale Growth (T-P-G) of convection
  - ✓ Large-scale variability modulate the DC by affecting the timing/location/vigor of TPG.
  - ✓ TPG processes over land and water are modulated differently to large-scale forcing, leading to different responses of DC.
- Need to systematically examine the influences of topographical scales (ocean basin width, mountain height,…) and surface fluxes (SST, soil moisture), etc.

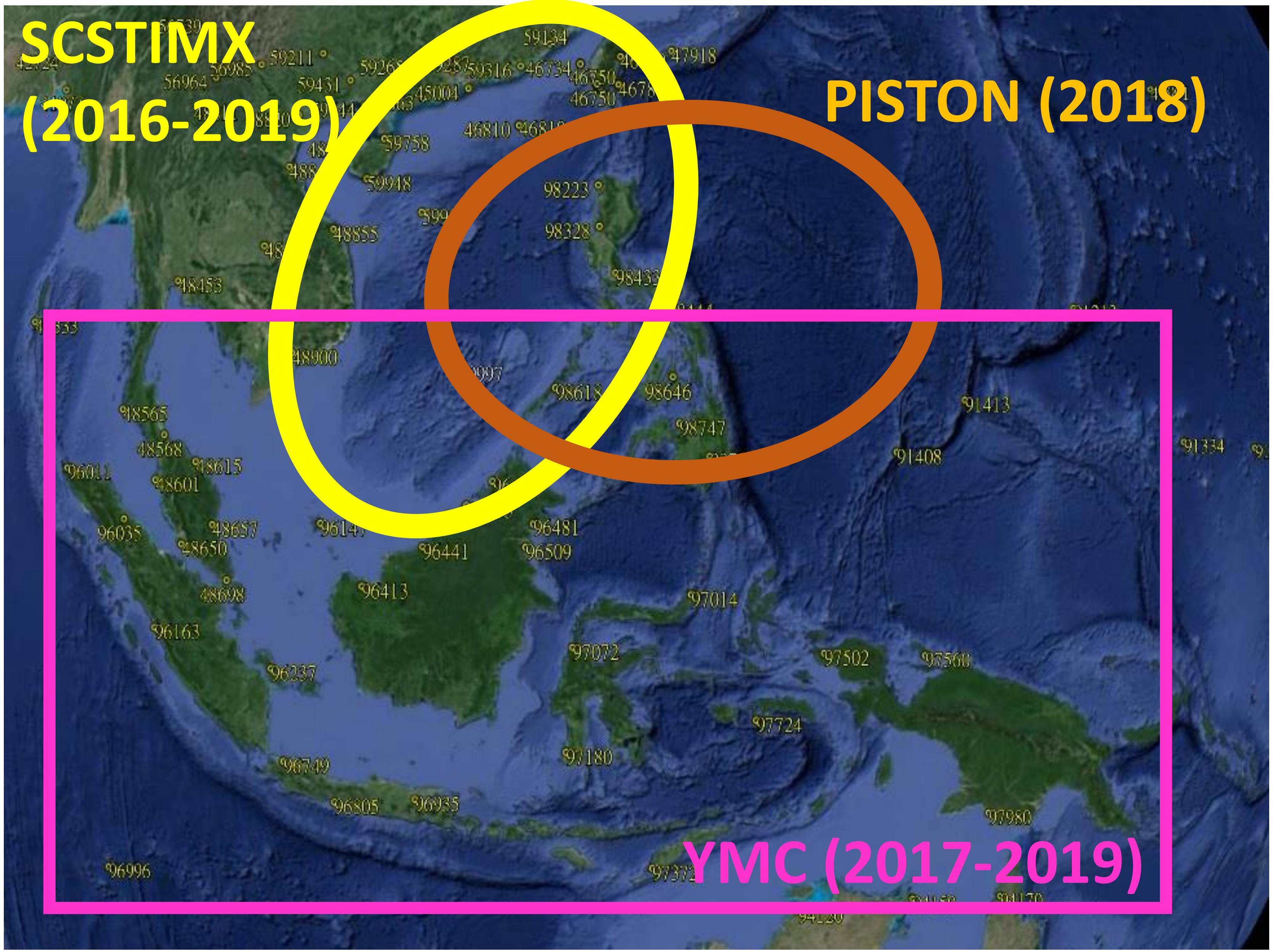
Next: Detailed case study using high resolution satellite observations

2016 South China Sea Summer Monsoon Onset (May 23-26)



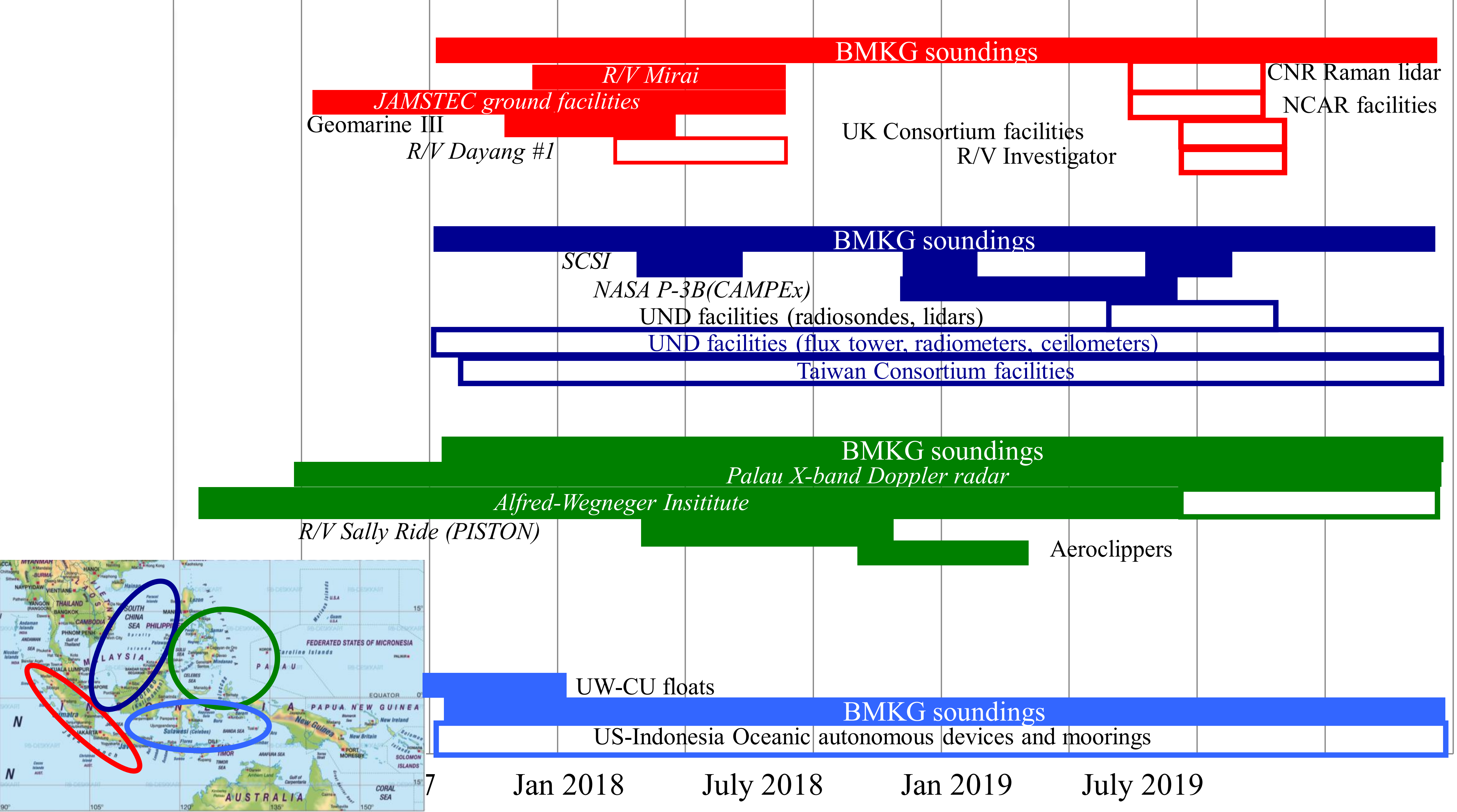


Next: The YMC, SCSTIMX (Taiwan), PISTON (US) Field Campaigns



YMC Implementation Plan

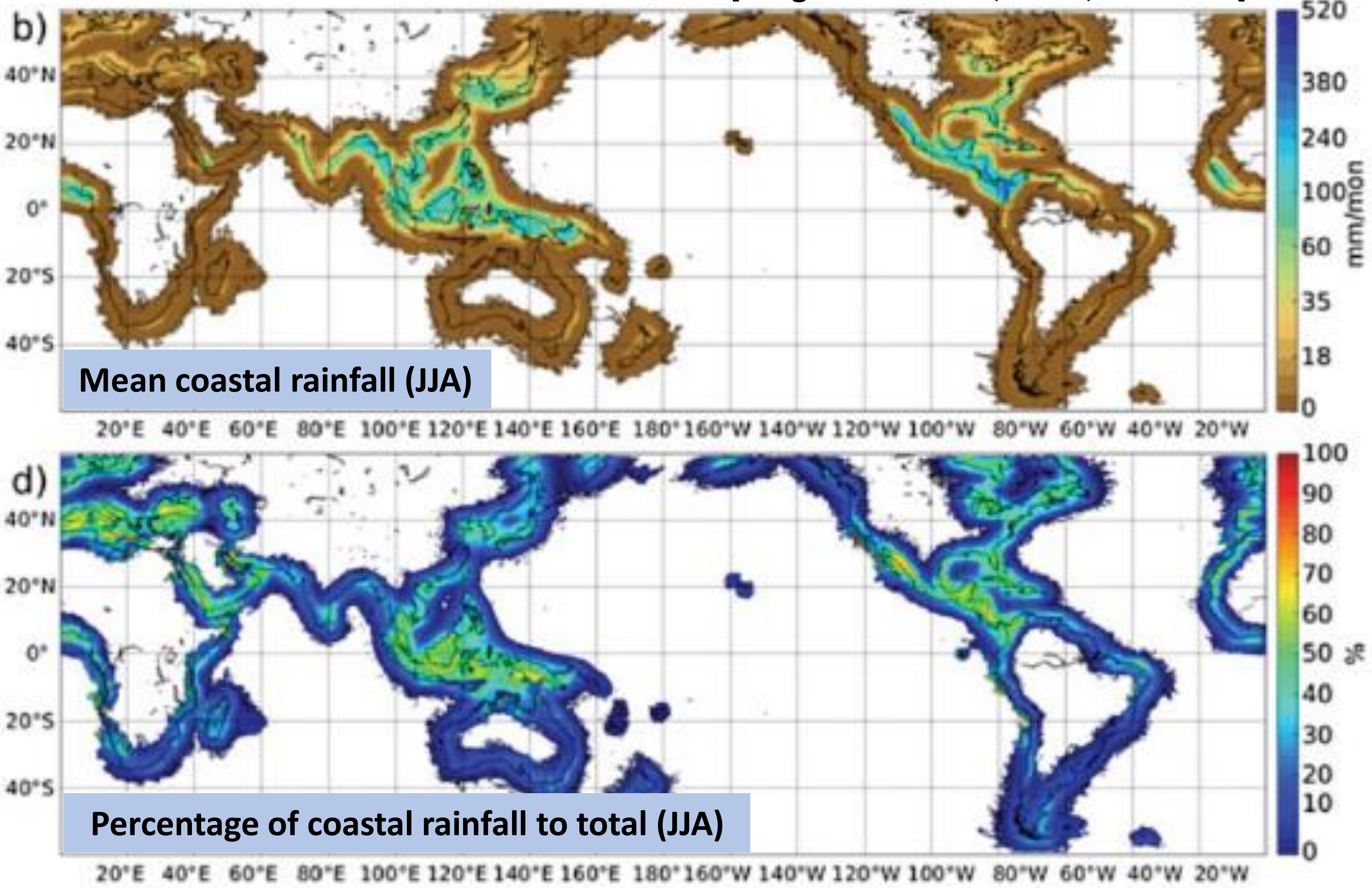
Tentative Deployment Timeline



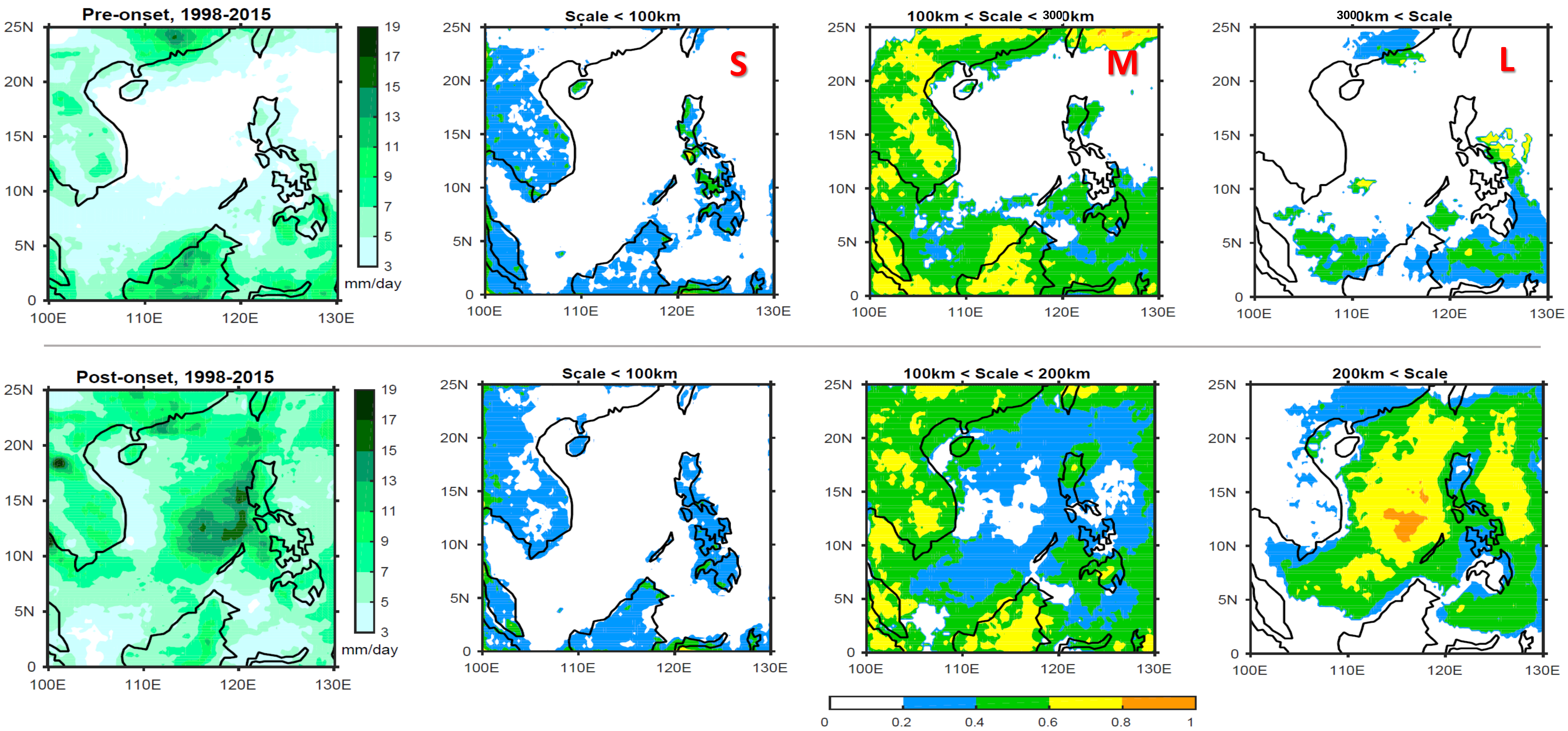
In real world, coastlines large organized convection

- Coastal circulations, generated by land-sea thermal contrast and orography, control the initiation and organization of convection systems
- Often exhibits strong diurnal cycle
- Sensitive to large-scale condition

[Bergemann et al., 2015, J Climate]



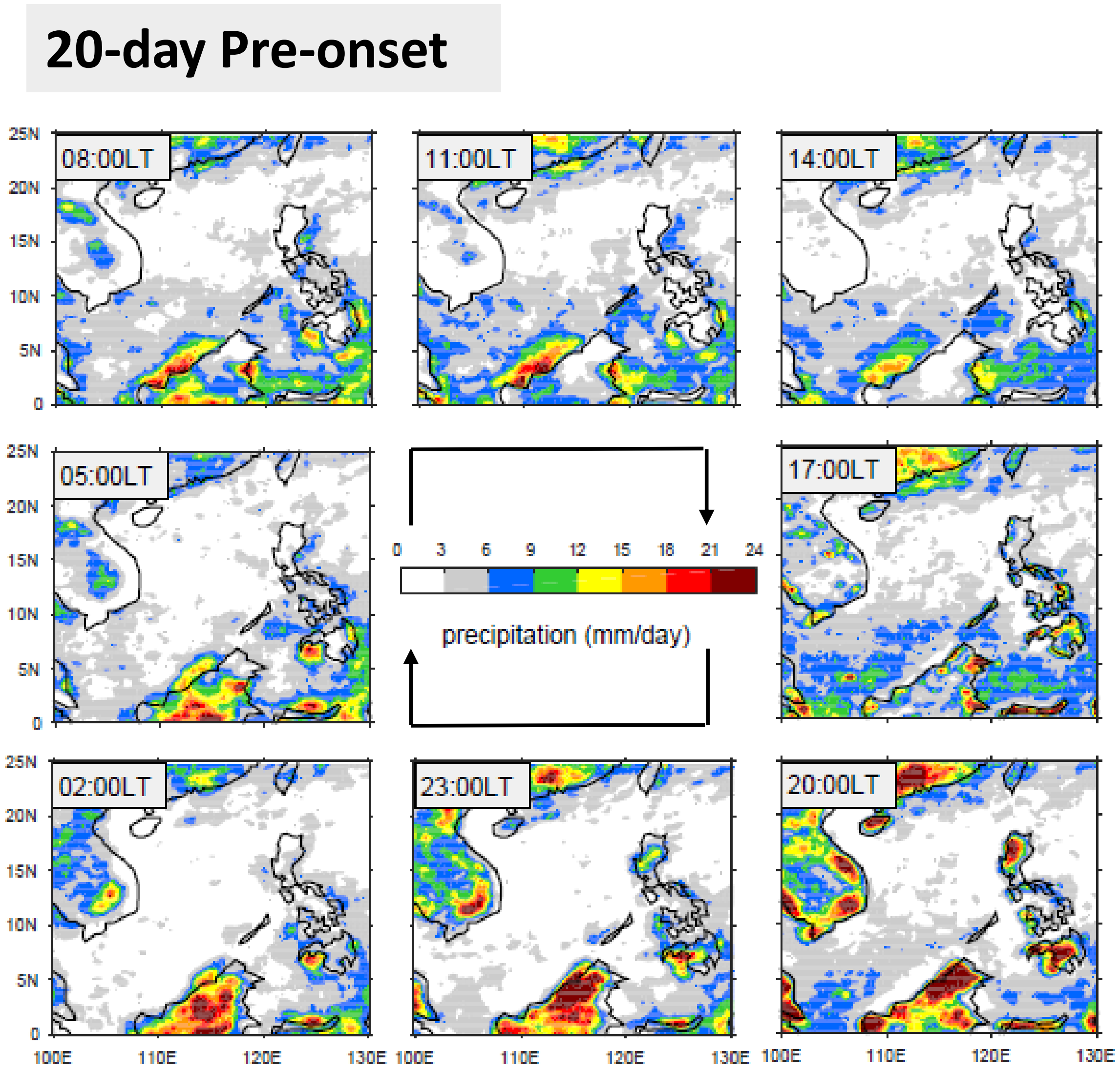
Contribution to precipitation from size category

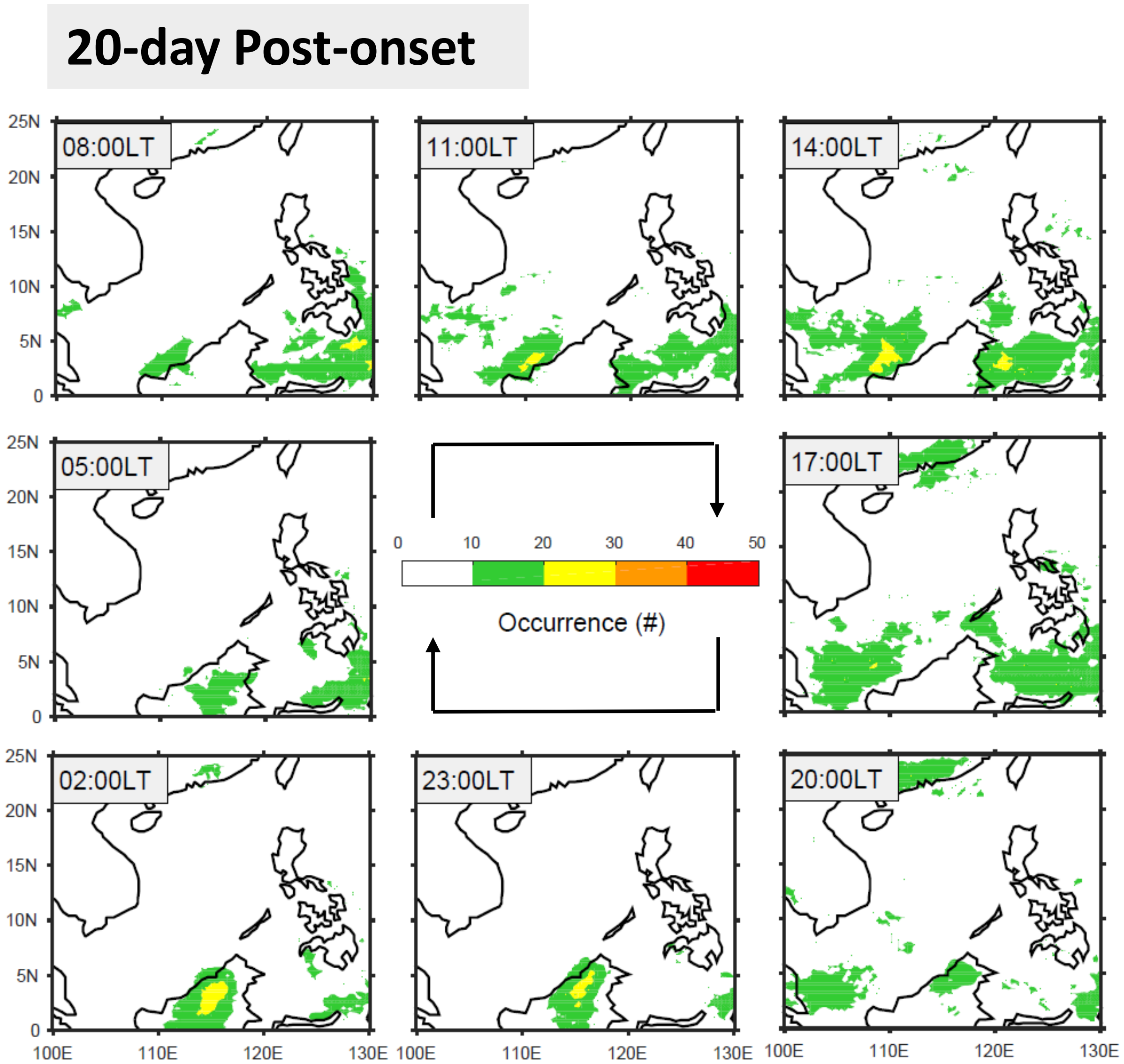


- Over land contribution mainly from medium systems (~50-60%)
- Post-onset contribution from extreme large systems is dominant (>60%) over the ocean

Pre-onset Diurnal Cycle

TRMM 1998-2015

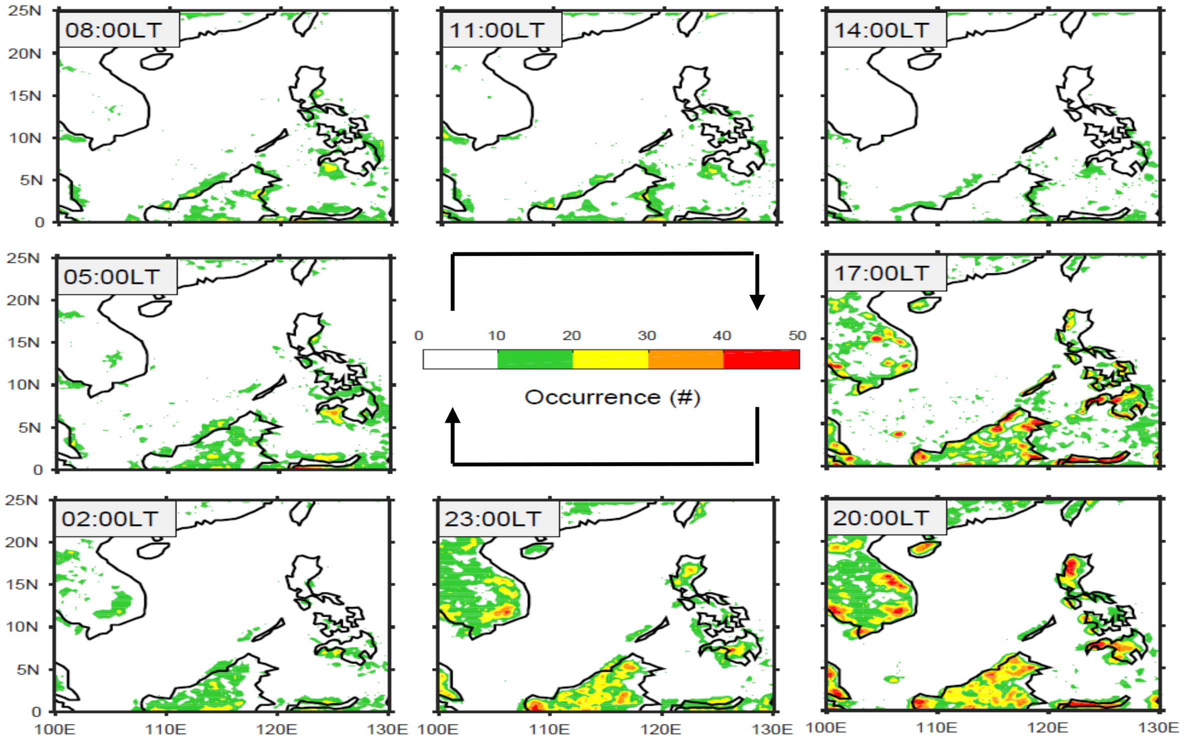




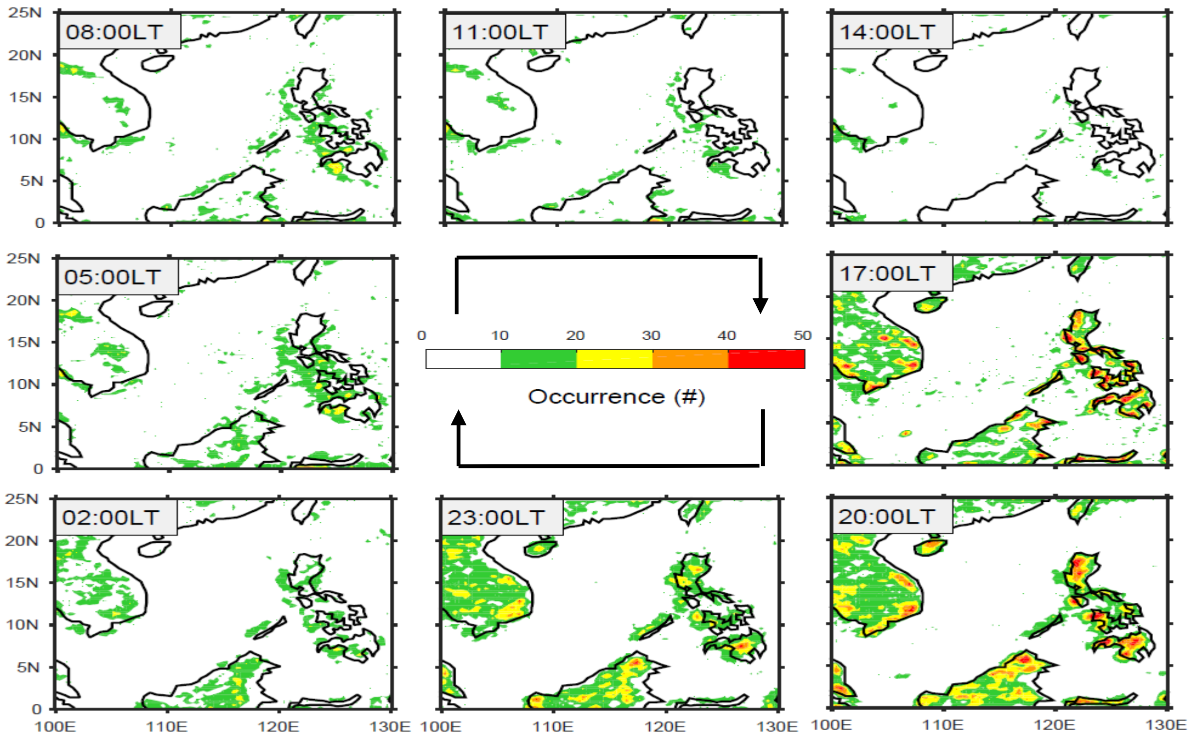
- Pre-onset diurnal cycle mainly over land, peak in the evening
- Post-onset diurnal cycle over both land (peak in evening) and ocean (peak in afternoon)

Diurnal cycle of precipitating system: S (<100 km)

Pre-onset



Post-onset

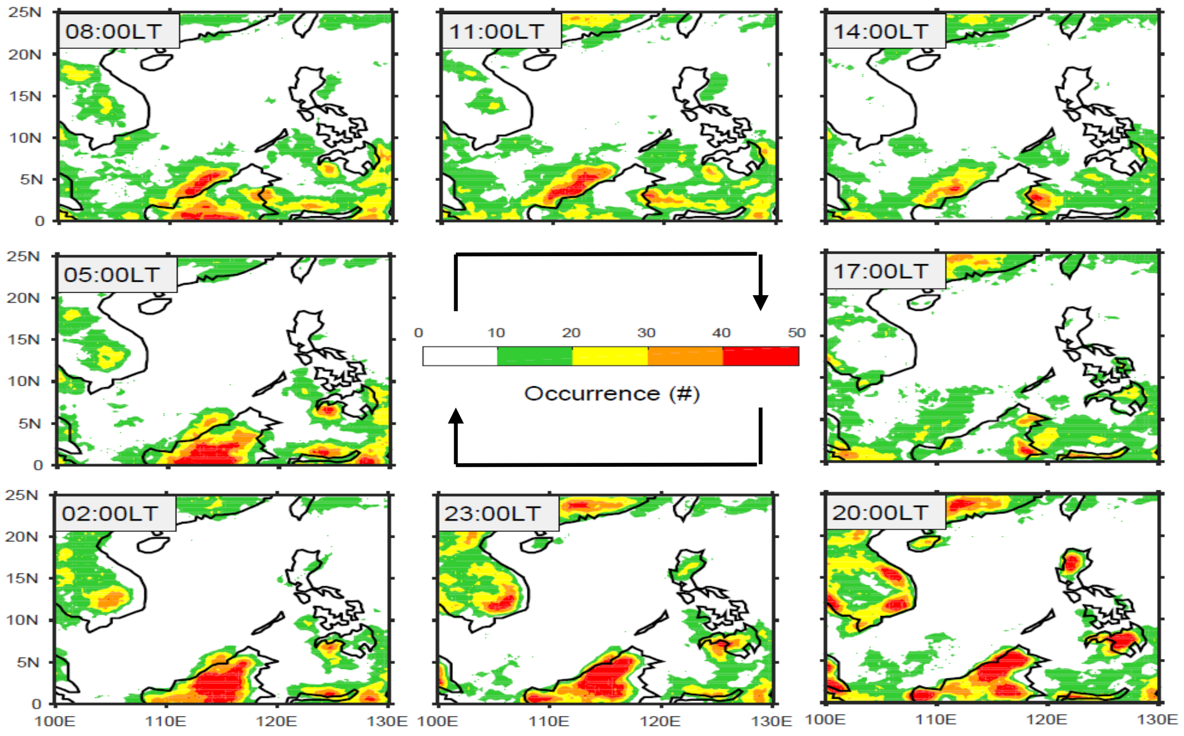


- Precipitating systems are almost located over land and occur during the evening
- No significant difference between pre-onset and post-onset

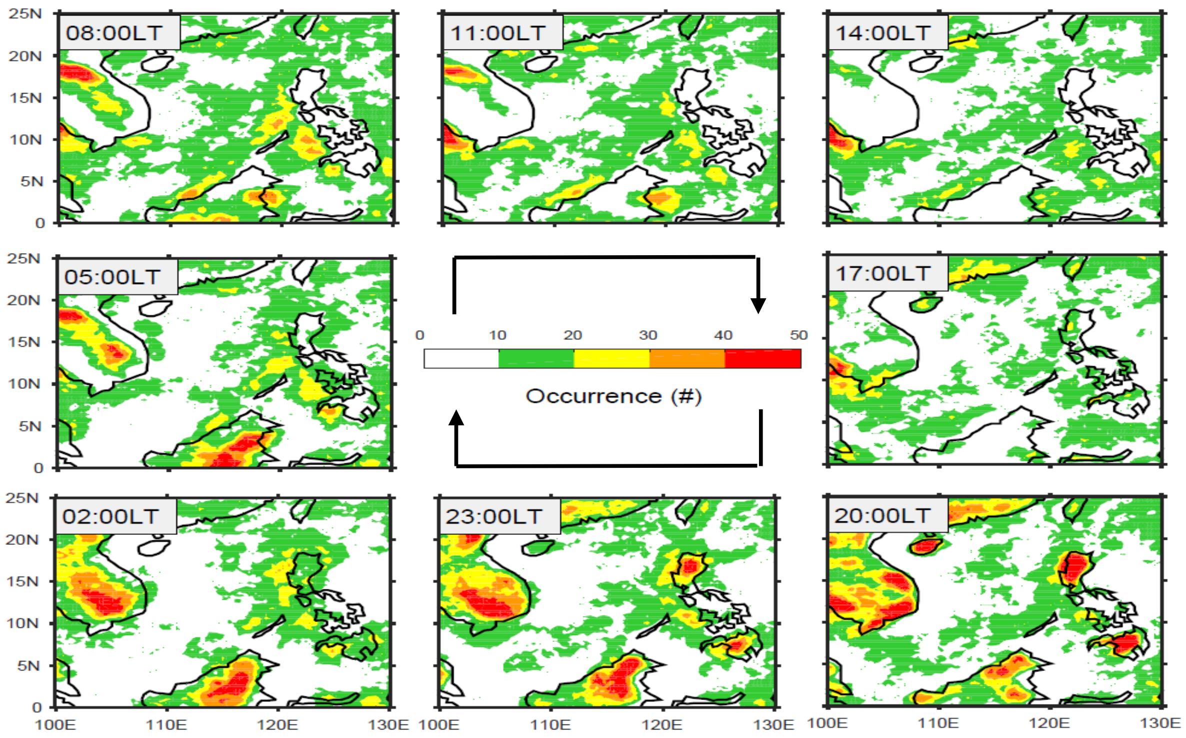
TRMM 1998-2015

Diurnal cycle of precipitating system: M(100~300 km)

Pre-onset



Post-onset

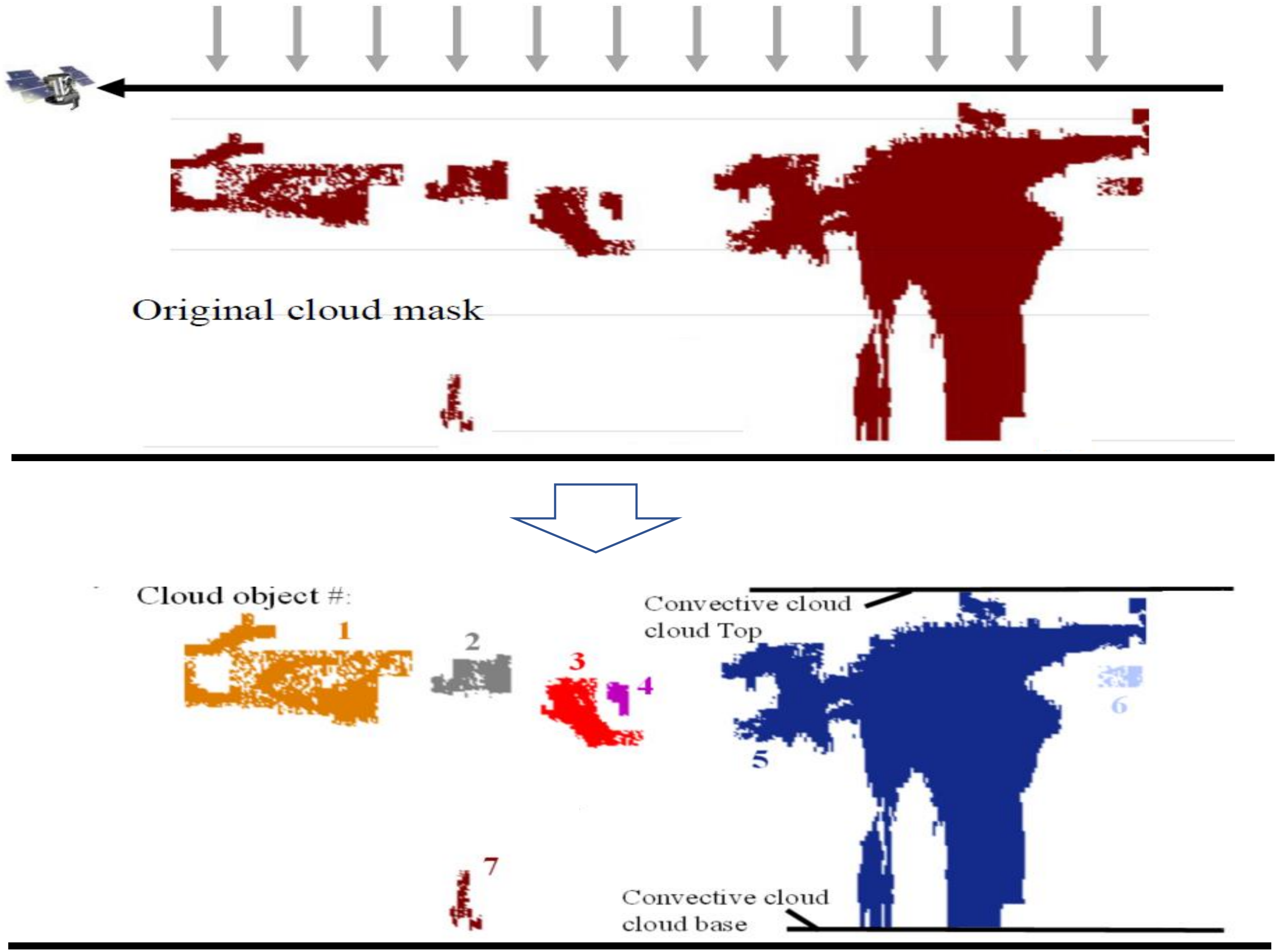


- Diurnal cycle peak in the morning (5~14LT) over the ocean , in the evening (17~2LT) over land
- Pre-onset mainly over Borneo; post onset over most land areas

TRMM 1998-2015

Quantifying the Size of Connected Cloud Object

- Contiguous cloudy pixels are identified as a cloud object (x-z cross section) using the 4-way connection method.
- Count and sort convective cloud objects by their sizes

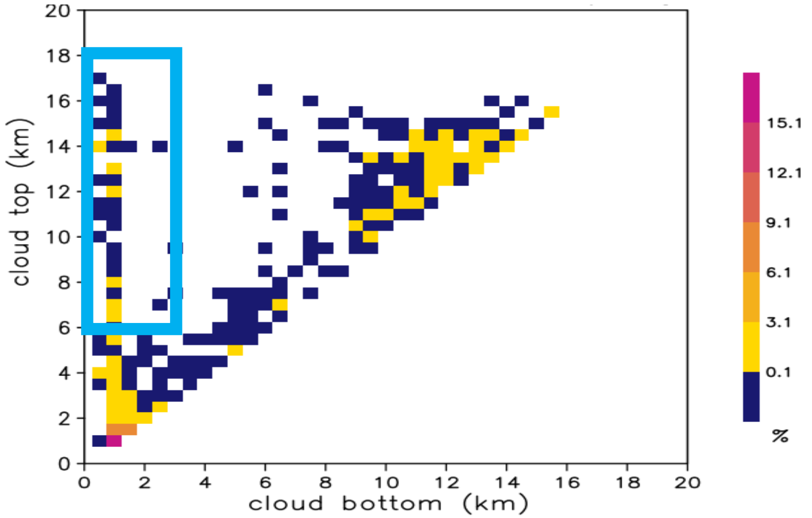


Cloud object size = (# of pixels) x (pixel size, 0.264 km^2)

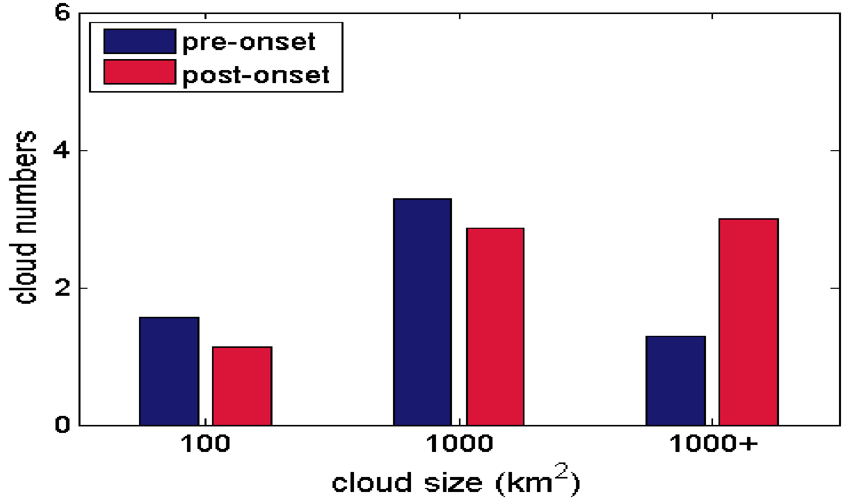
All Cloud Object Base-Top Height Joint PDF

Convective Cloud Size Distribution

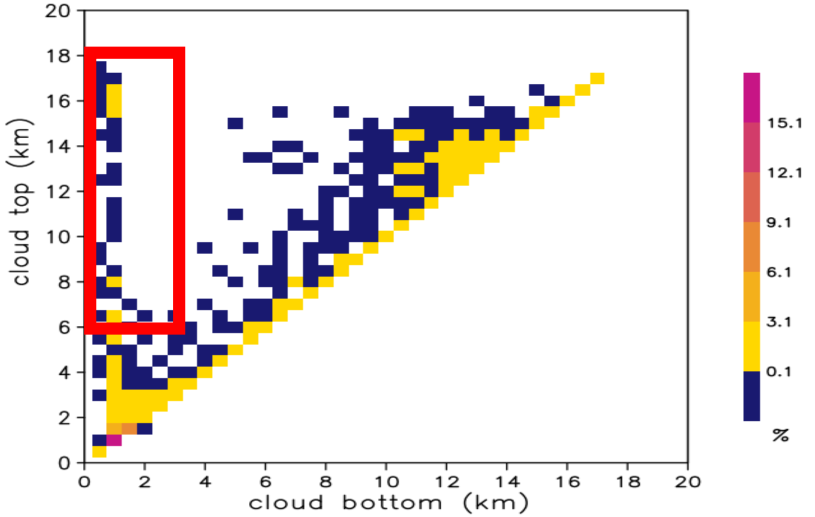
Pre-Onset



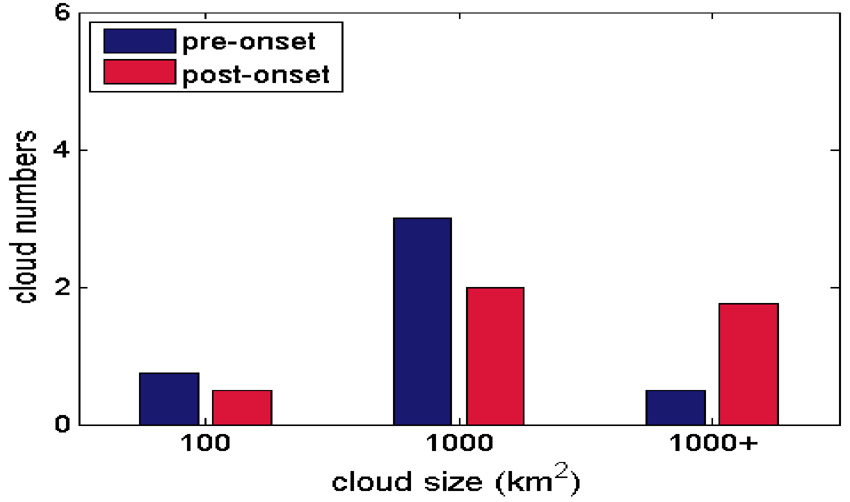
Daytime Overpass (~1:30pm)



Post-Onset



Nighttime Overpass (~1:30am)



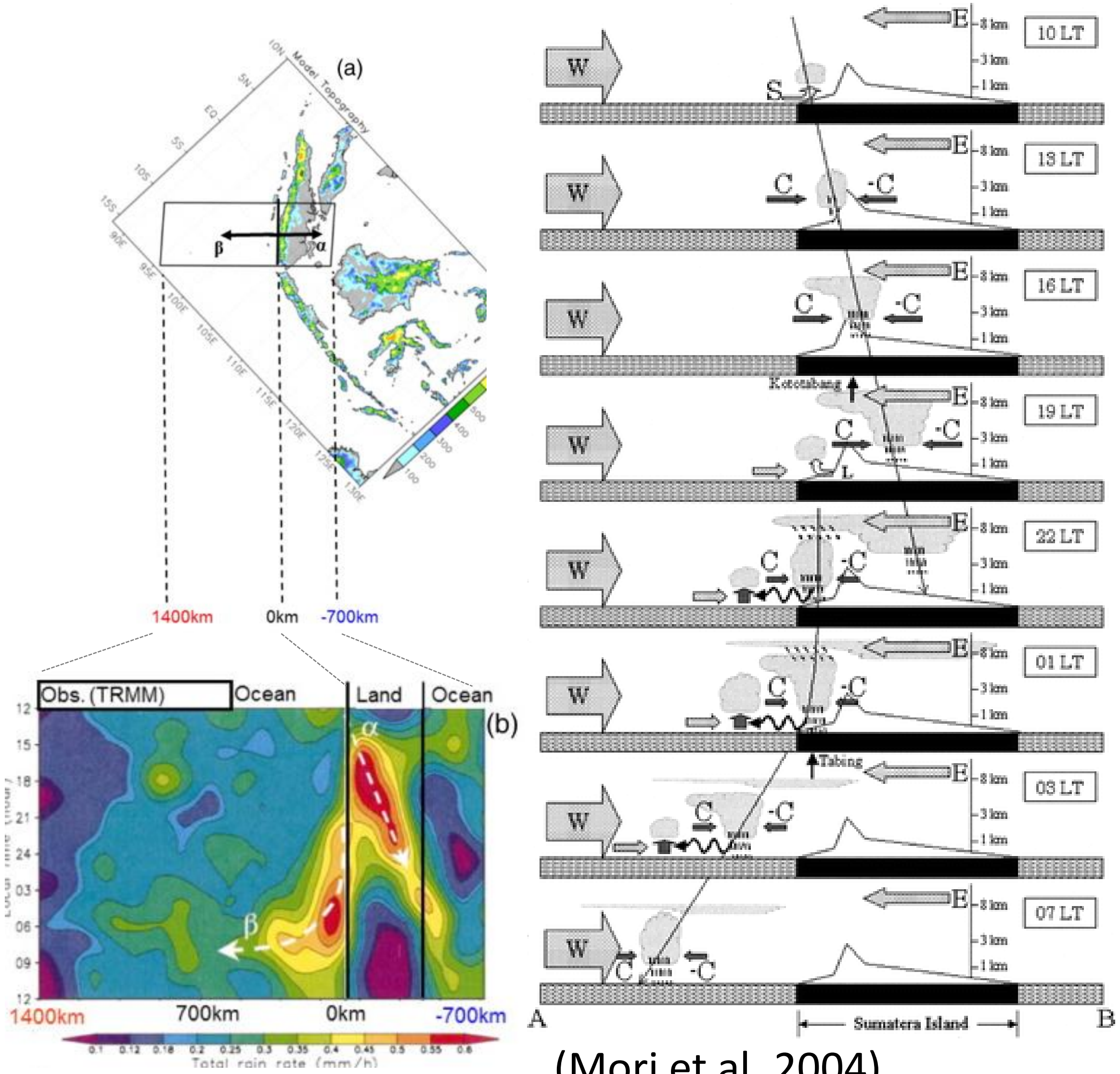
Cloud Object Base < 3 km and
Cloud Object Top > 6 km

Data :
GEOPROF CPR cloud mask

12.5-17.5°N, 110-120°E

Year of Maritime Continent (YMC, 2017-2019) – Scientific Theme 1: Diurnal Cycle of MC Convection

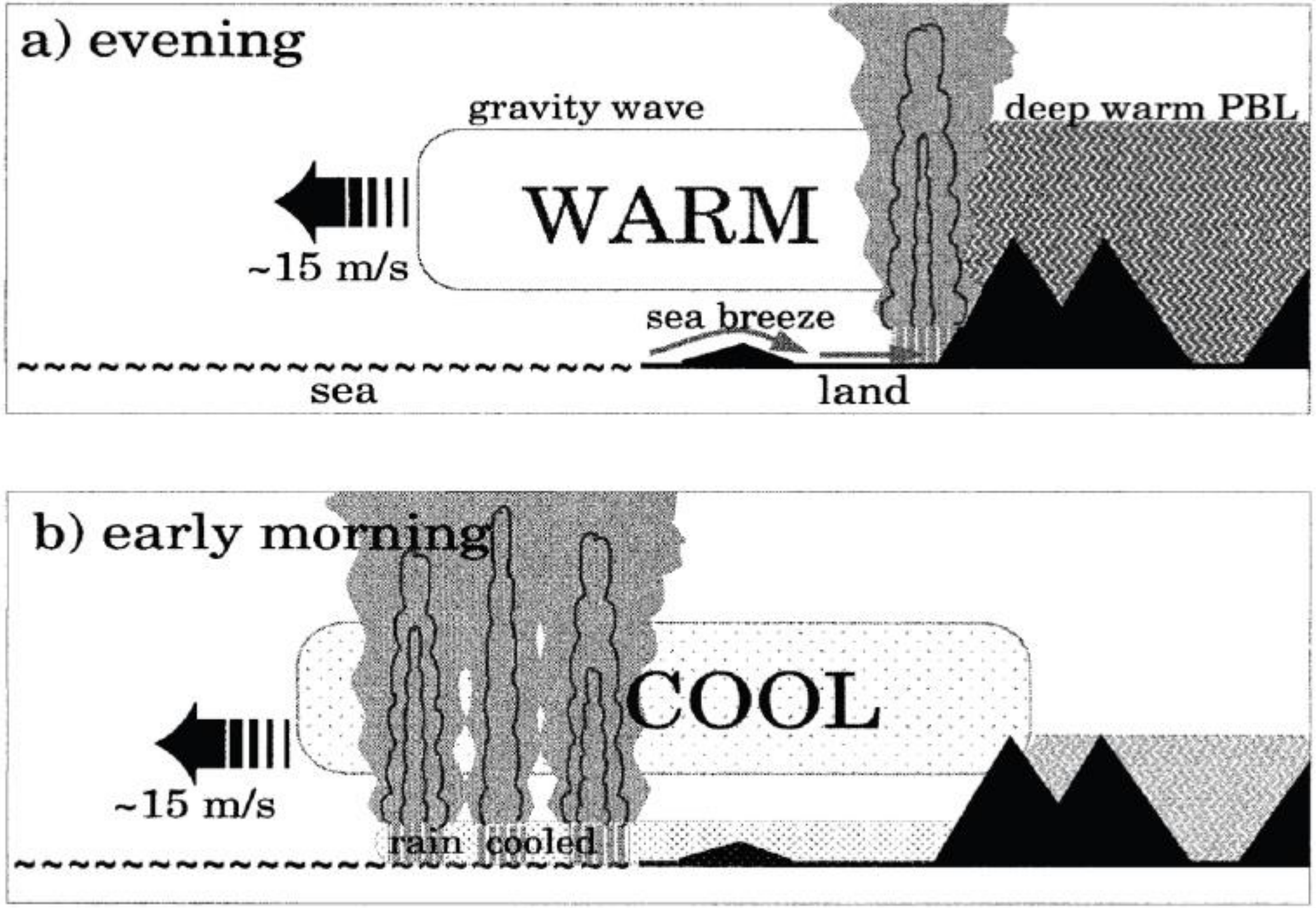
- To advance understanding of physical processes governing the multi-scale interactions of convection over the MC under the influence of the complex land-sea distribution and topograph



(Mori et al.,2004)

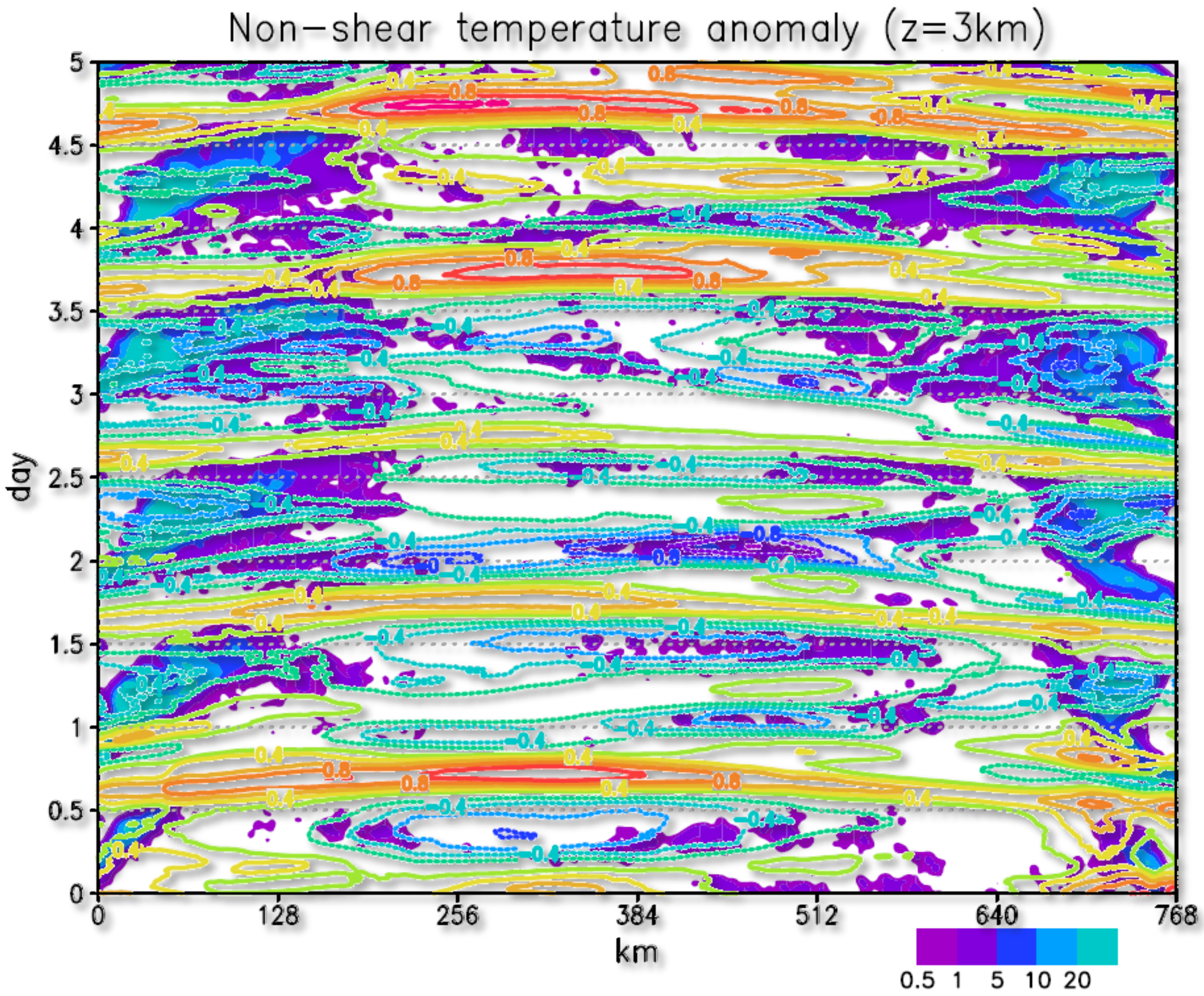
The role of mixed layer gravity waves on offshore convection propagation

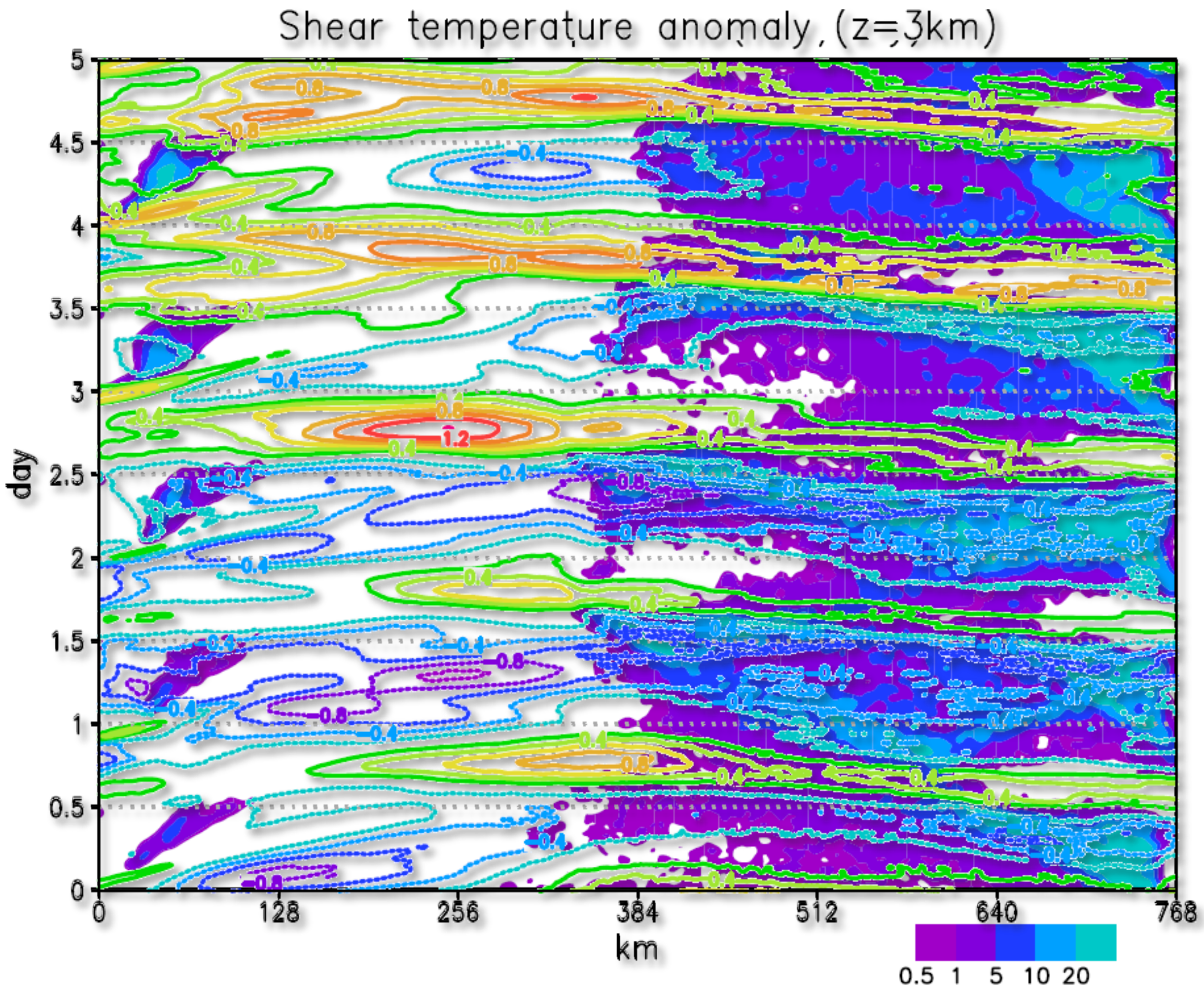
- [Mapes et al., 2003, MWR]: Propagation of offshore convection is related to the destabilization by the gravity waves generated by the diurnally elevated mixed layer over coastal mountain terrain.



The role of mixed layer GW on offshore convection propagation

Use temperature anomaly at 700 hPa (contour) as signal of GW following Mapes et al., [2003]





- Cold anomaly (GW destabilization effect) is generally in phase with strong precipitation within 150 km offshore, and only in the windward shore in the case with shear.
- Other mechanisms may be responsible for convection propagation further into open ocean (mesoscale processes?)