Coastal convection

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ICTP

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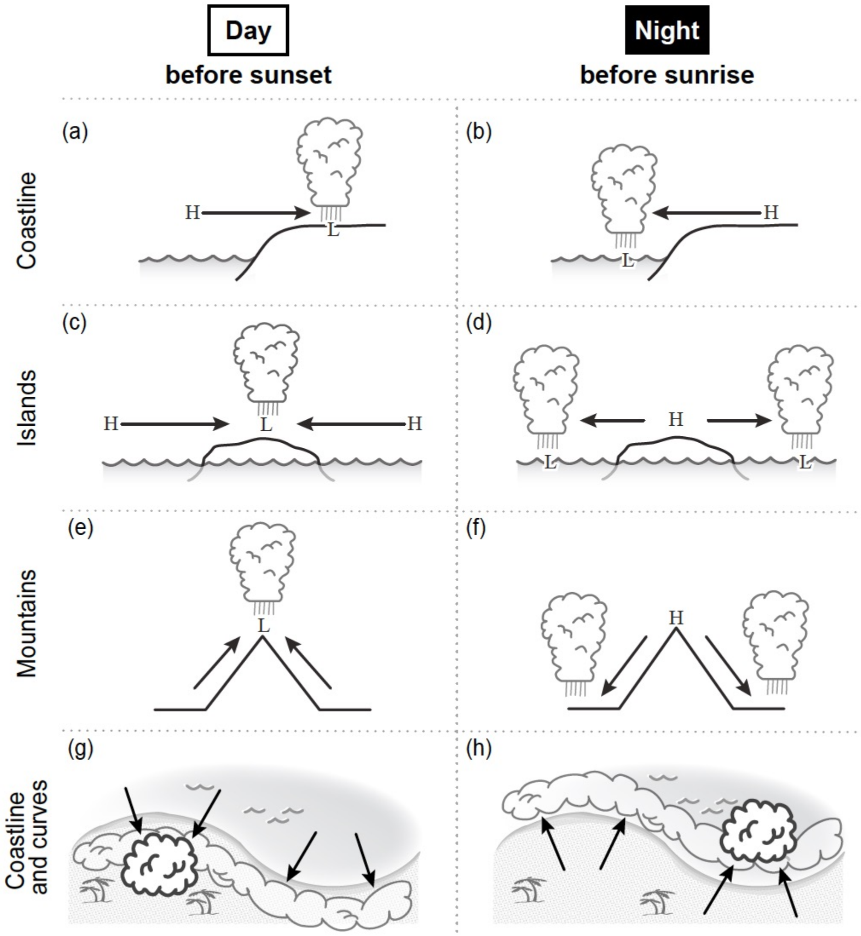
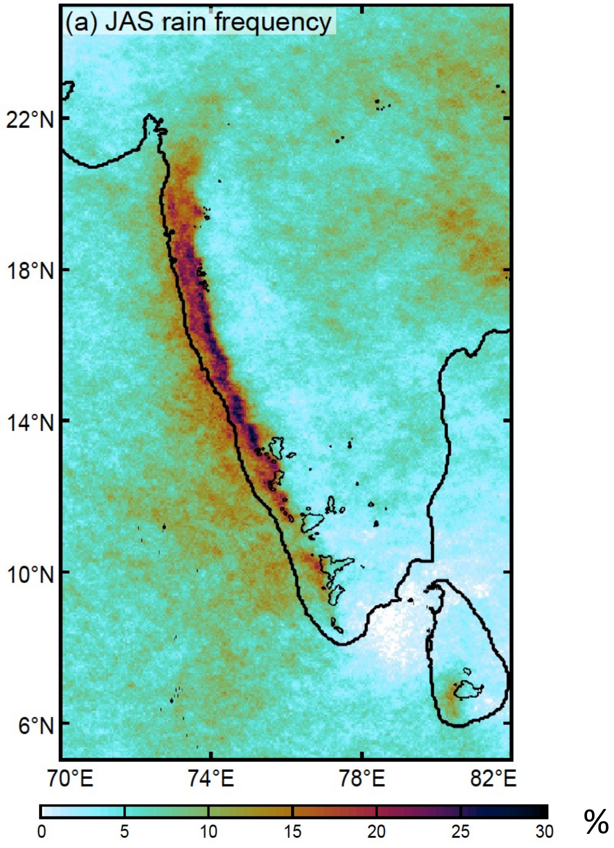
Coastal diurnal circulations



Sea/land breeze

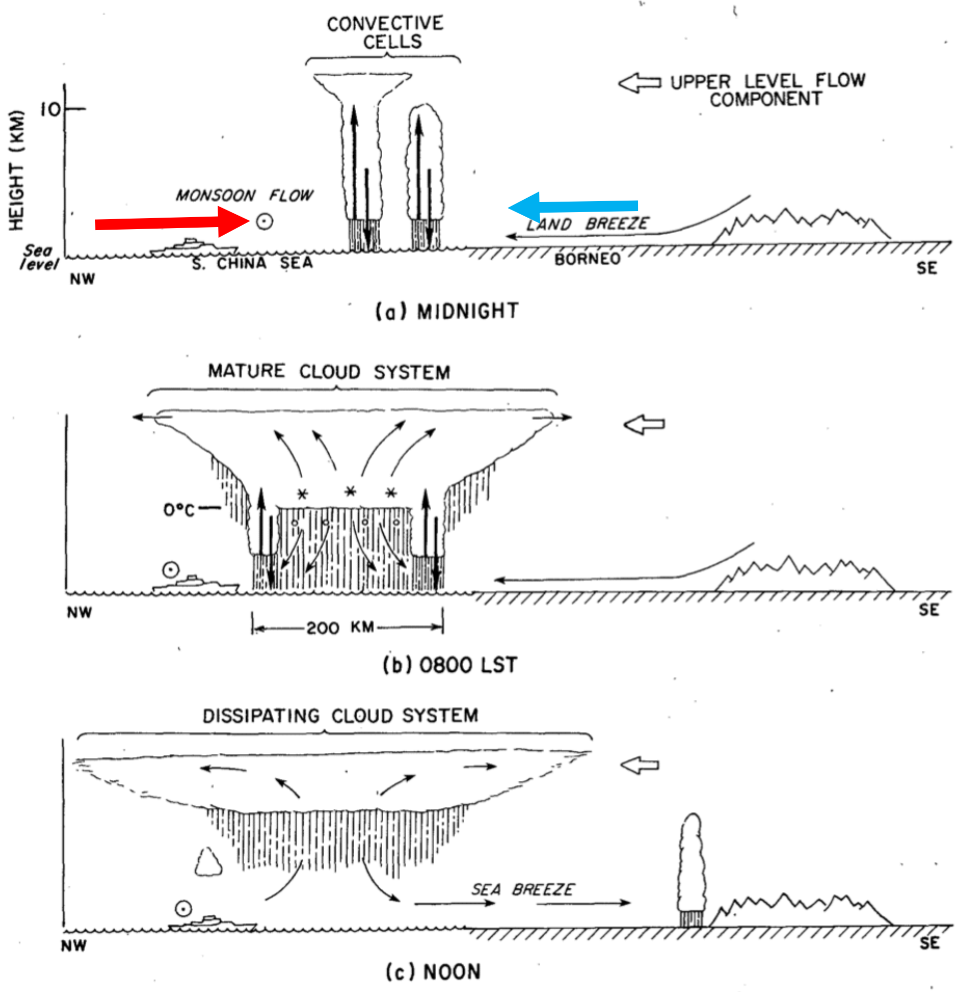
Valley/mountain breeze

TRMM PR rain occurrence



Biasutti et al. (2011)

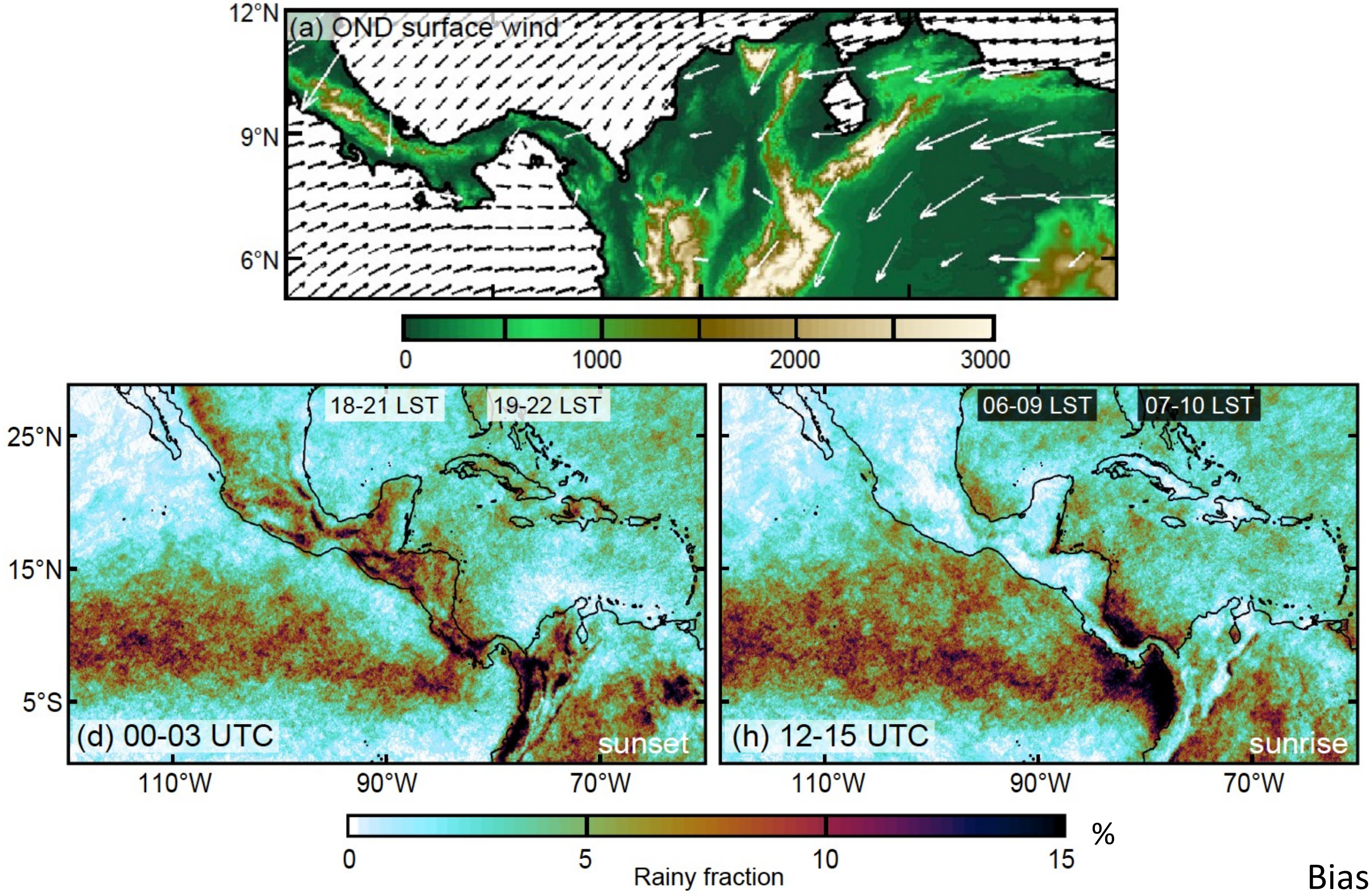
Land breeze convergence and convective evolution



- Convective cells can form at the convergence of the land breeze and the large-scale low-level flow
- Systems then often evolve into mature MCSs as they propagate offshore, dissipating by midday once winds convert to onshore

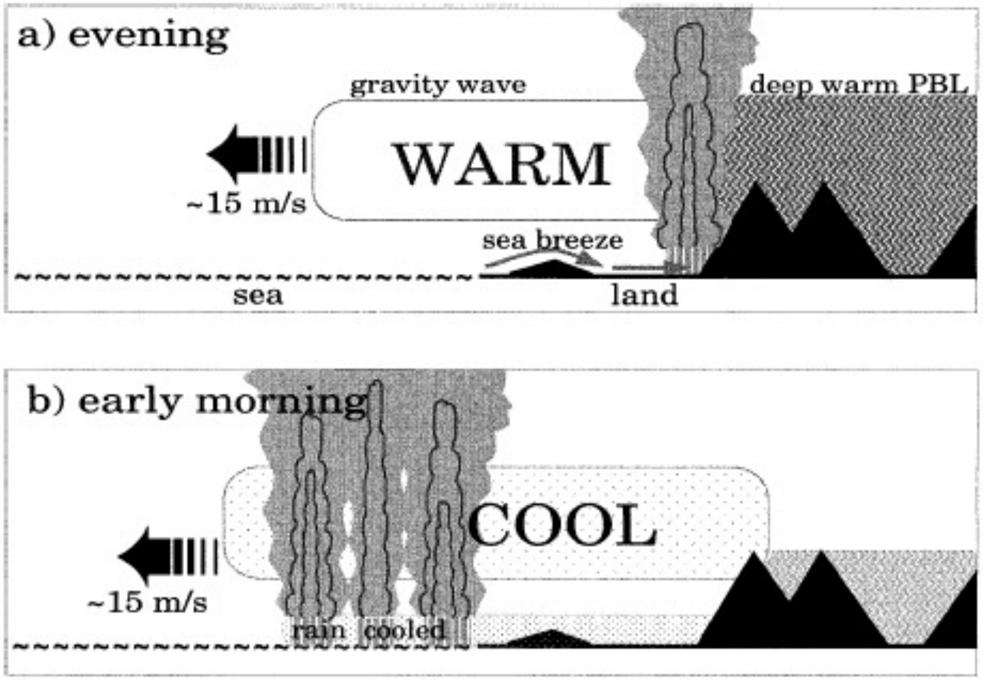
Houze et al. (1981)

Is it really just sea/land and valley/mountain breezes?



Biasutti et al. (2011)

Gravity waves and their impact on convection

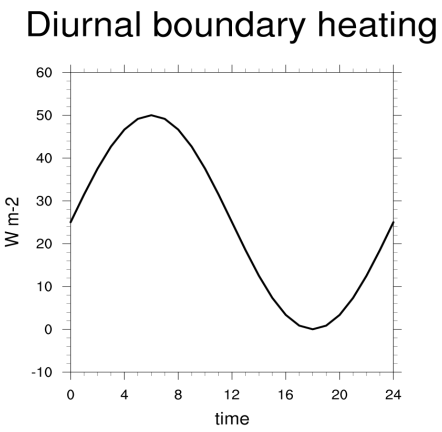


- Small temperature changes near 800 hPa driven by gravity waves forced by daytime heating over mountains changes sign of atmospheric buoyancy from negative (inhibited) to positive (convecting) with a propagation speed of 15 m/s
- This change in buoyancy can promote convective growth

Mapes et al. (2003)

Idealized gravity wave response to diurnal BL heating

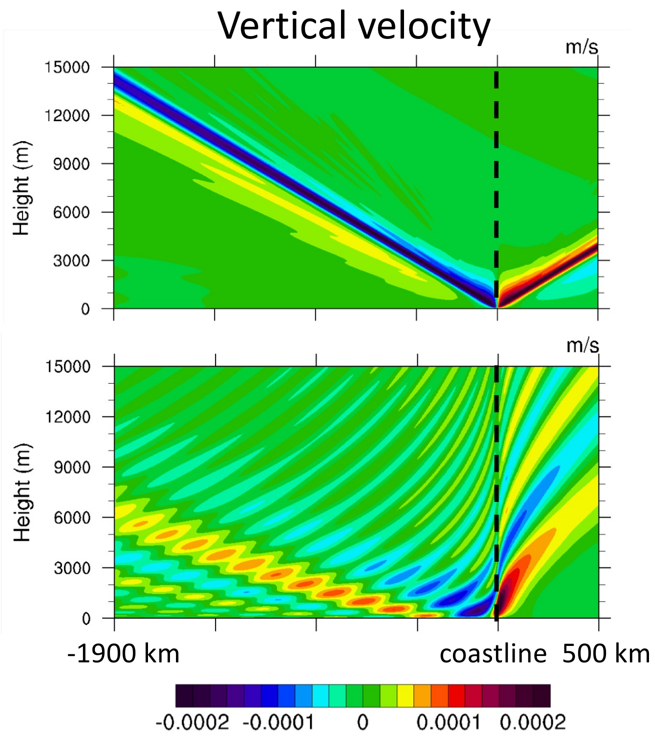
Diurnally oscillating heating below 1 km imposed at the coast



2D dry model

Resting background state

Constant background state



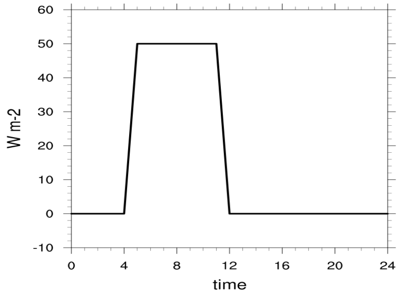
Courtesy of A. O’Flanagan

- A ray extends out from the coast, background winds modify the wave ray

*Expanding upon linear theory of land breeze near equator by Rotunno (1983) and Qian et al. (2009)

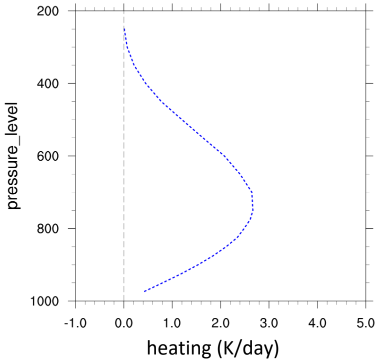
Idealized gravity wave response to deeper pulsed heating

Pulsed heating



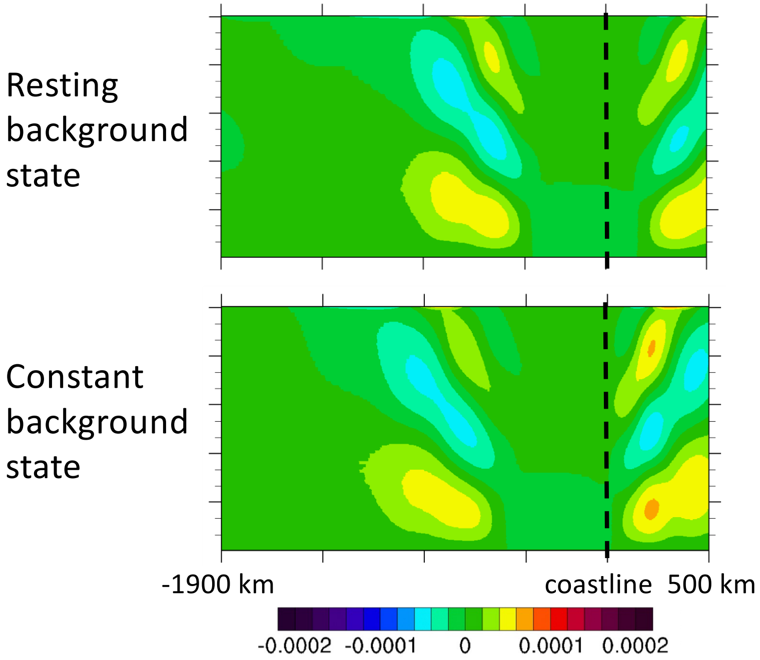
Heating imposed in a deeper layer for 2 hours each day in the late afternoon

Vertical heating profile

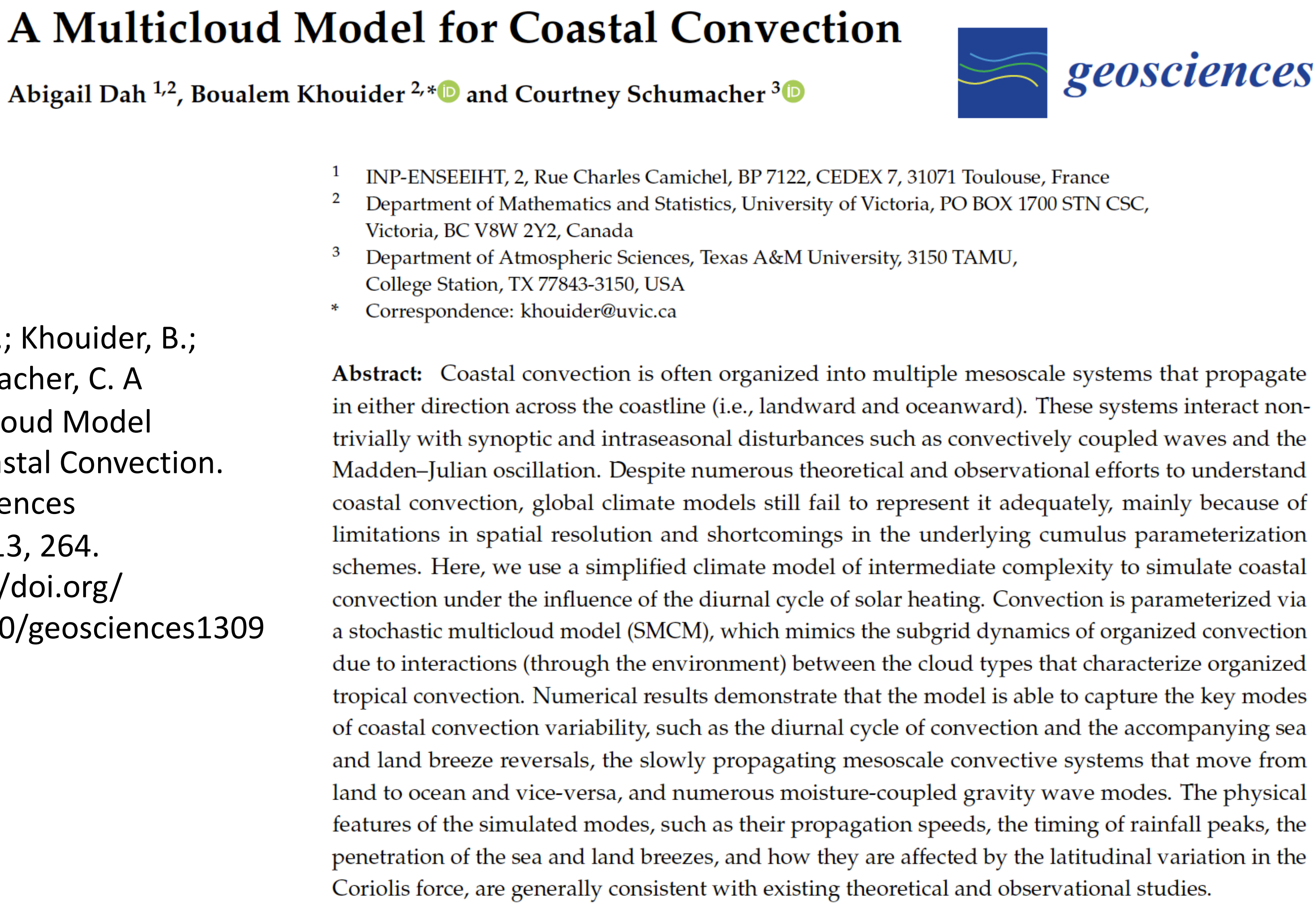


[2D dry model]

Temperature anomalies



- Wave response takes the form of wave packets propagating outward from the coast, producing regions of warmer air near the ground and colder air aloft
- Which type of forcing is more important to offshore convective development?



A Multicloud Model for Coastal Convection

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Abstract: Coastal convection is often organized into multiple mesoscale systems that propagate in either direction across the coastline (i.e., landward and oceanward). These systems interact non-trivially with synoptic and intraseasonal disturbances such as convectively coupled waves and the Madden–Julian oscillation. Despite numerous theoretical and observational efforts to understand coastal convection, global climate models still fail to represent it adequately, mainly because of limitations in spatial resolution and shortcomings in the underlying cumulus parameterization schemes. Here, we use a simplified climate model of intermediate complexity to simulate coastal convection under the influence of the diurnal cycle of solar heating. Convection is parameterized via a stochastic multicloud model (SMCM), which mimics the subgrid dynamics of organized convection due to interactions (through the environment) between the cloud types that characterize organized tropical convection. Numerical results demonstrate that the model is able to capture the key modes of coastal convection variability, such as the diurnal cycle of convection and the accompanying sea and land breeze reversals, the slowly propagating mesoscale convective systems that move from land to ocean and vice-versa, and numerous moisture-coupled gravity wave modes. The physical features of the simulated modes, such as their propagation speeds, the timing of rainfall peaks, the penetration of the sea and land breezes, and how they are affected by the latitudinal variation in the Coriolis force, are generally consistent with existing theoretical and observational studies.

Dah, A.; Khouider, B.;
Schumacher, C. A
Multicloud Model
for Coastal Convection.
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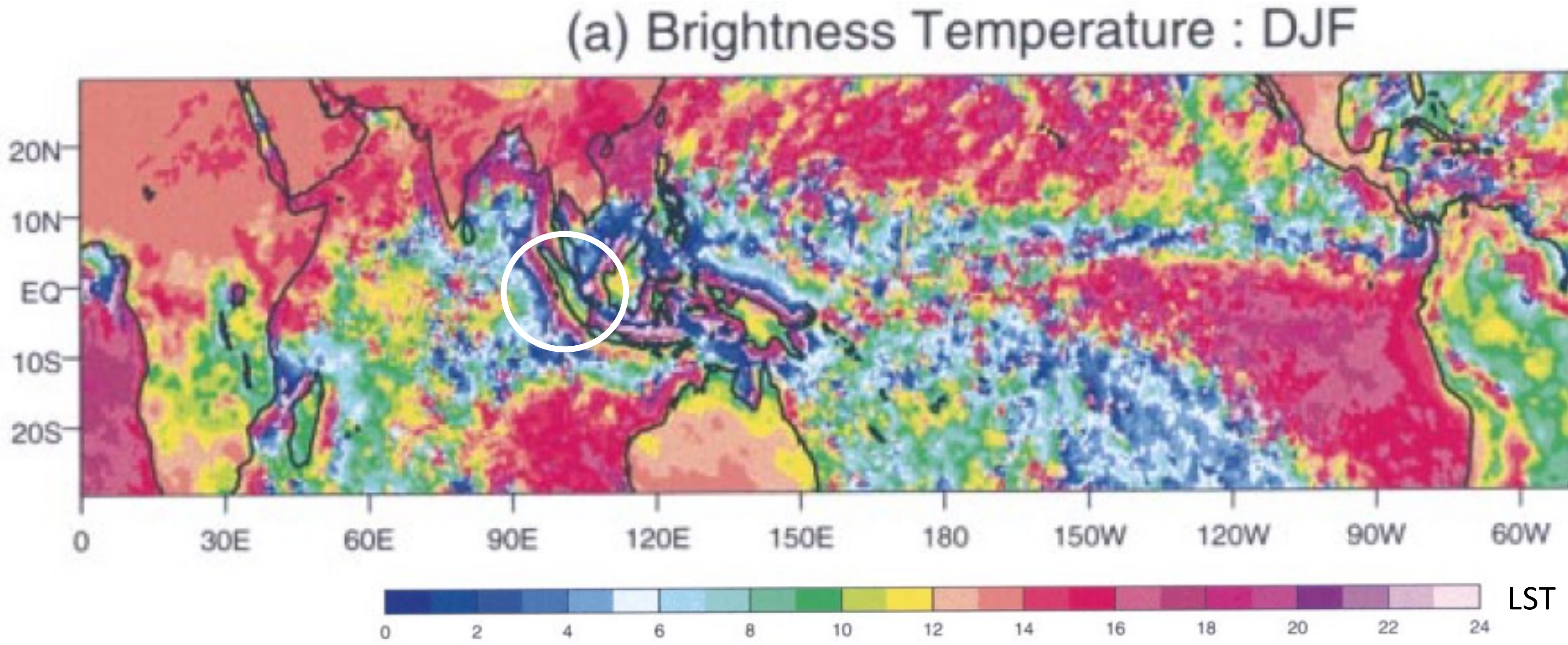
0264

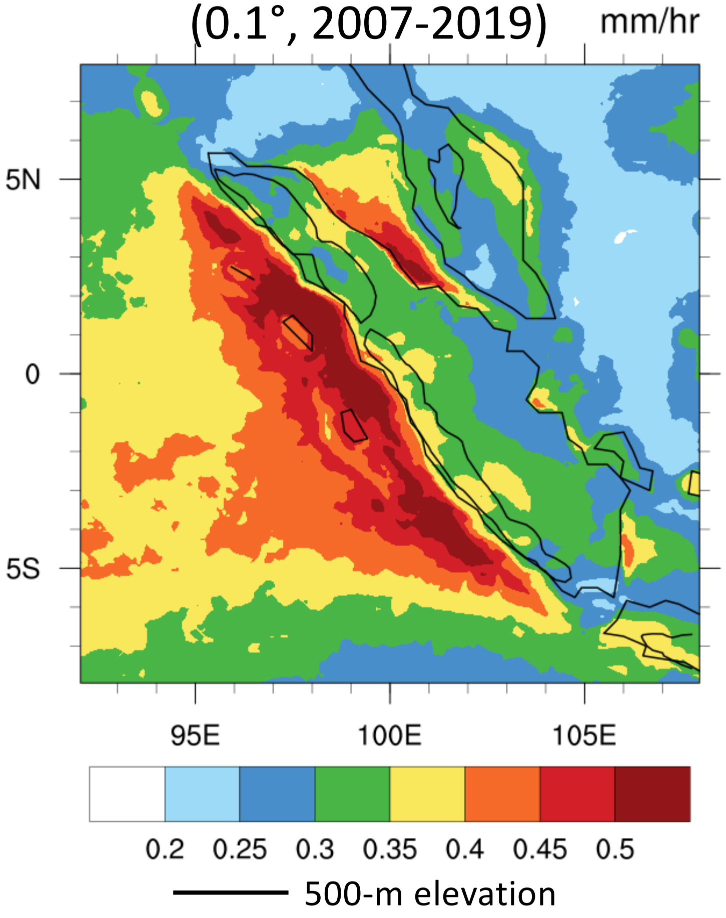
Diurnal phase from IR



Regardless of mechanism, a rich diversity of coastal convective variability happens near tropical coasts at the diurnal time scale

Yang and Slingo (2001)

Annual mean rainfall over Sumatra



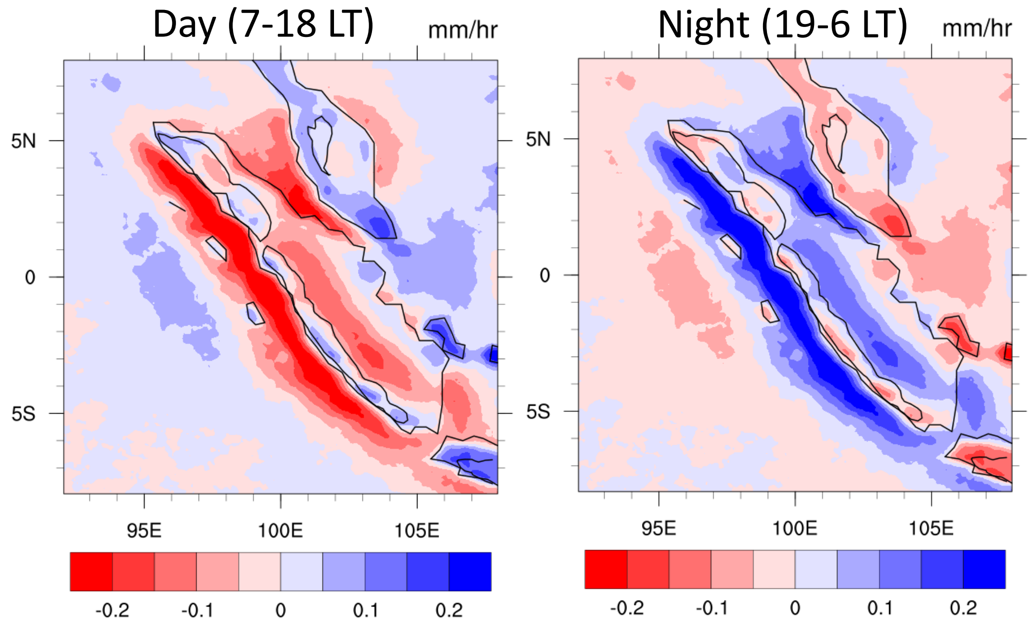
IMERG rainfall
(0.1°, 2007-2019)

- TRMM/GPM IMERG is consistent with many existing satellite climatologies*, higher resolution measurements help isolate orographic patterns
- Offshore (just west of mountains to ~150 km offshore) – highest rainfall (12 mm/d)
- Over mountains – moderate rainfall (8 mm/d)
- East of mountains – least rainfall (6-7 mm/d)

*e.g., Yang and Slingo (2001), Kikuchi and Wang (2008), Mori et al. (2004), Love et al. (2011), Biasutti et al. (2012), Peatman et al. (2014), Birch et al. (2016), Ling et al. (2019), Sakaeda et al. (2020)

Diurnal rainfall over Sumatra

IMERG rainfall anomalies



- Rainfall is enhanced over mountains during daytime and is enhanced to the west and east of mountains in the evening and early morning

What is the driver of nocturnal offshore rainfall propagation?

- *Land breeze* (Houze et al. 1981, Ohsawa et al. 2001, Mori et al. 2004, Biasutti et al. 2012, etc.)
  - What are the characteristics of the land breeze?
- *Gravity waves* (Mapes et al. 2003, Love et al. 2011, Vincent and Lane 2016, Yokoi et al. 2017, etc.)
  - Is boundary layer or deeper pulsed heating more important?

Past studies of nocturnal offshore rainfall propagation speed from West Sumatra

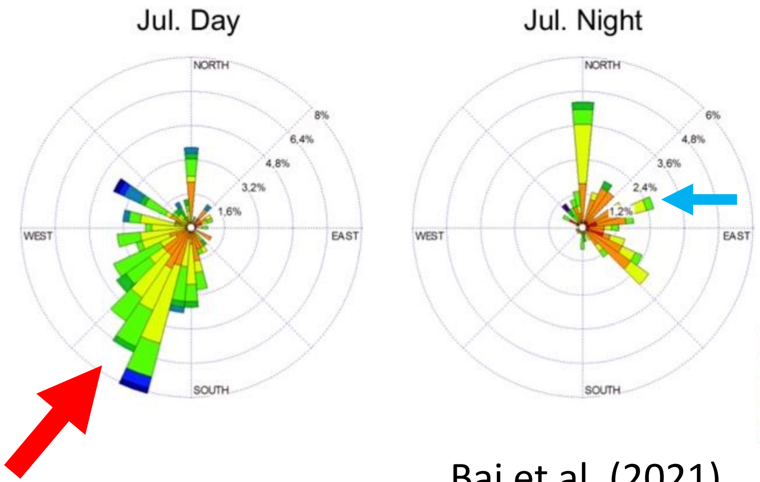
- 10 m/s over the Maritime Continent from CLAUS (Yang and Slingo 2001)
- 10 m/s off the west coast of Sumatra from TRMM (Mori et al. 2004)
- 10 m/s over the Maritime Continent from TRMM (Kikuchi and Wang 2008)

- 4 m/s off the west coast of Sumatra from X-band Doppler Radar (Mori et al. 2011)
- 3-5 m/s off the west coast of Sumatra from WRF, 7 m/s from TRMM (Love et al. 2011)
- 8 m/s over sea, 3-3.5 m/s around the west coast of Sumatra from Pre-YMC (Yokoi et al. 2017)

Thus, satellite IR studies have observed a faster offshore rainfall speed (~10 m/s), while recent radar and high-res model studies have seen a slower speed (~5 m/s)

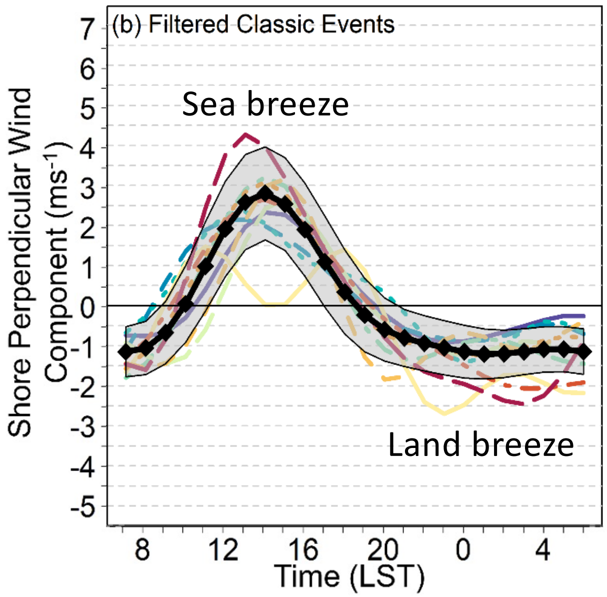
Land breeze characteristics over West Sumatra

BMKG
obs



Bai et al. (2021)

- Surface observations from Padang show weak offshore winds (< 3 m/s) at night (i.e., existence of a land breeze)

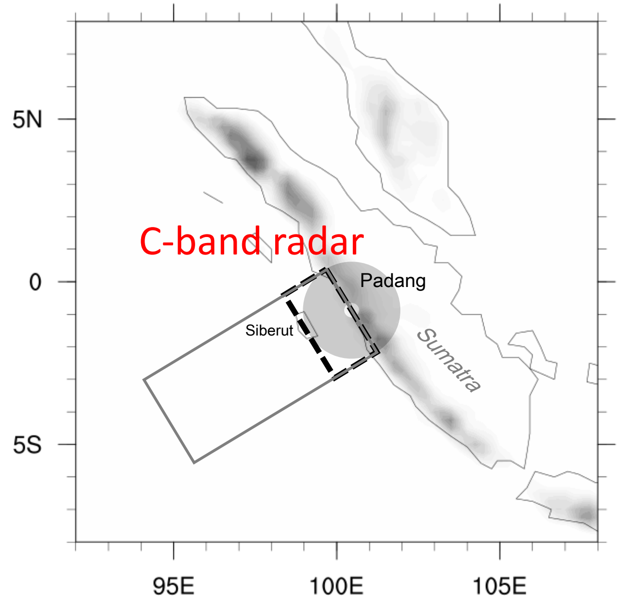


North (2023)

- Surface observations from Bengkulu show an offshore diurnal component of wind every day during 2018!

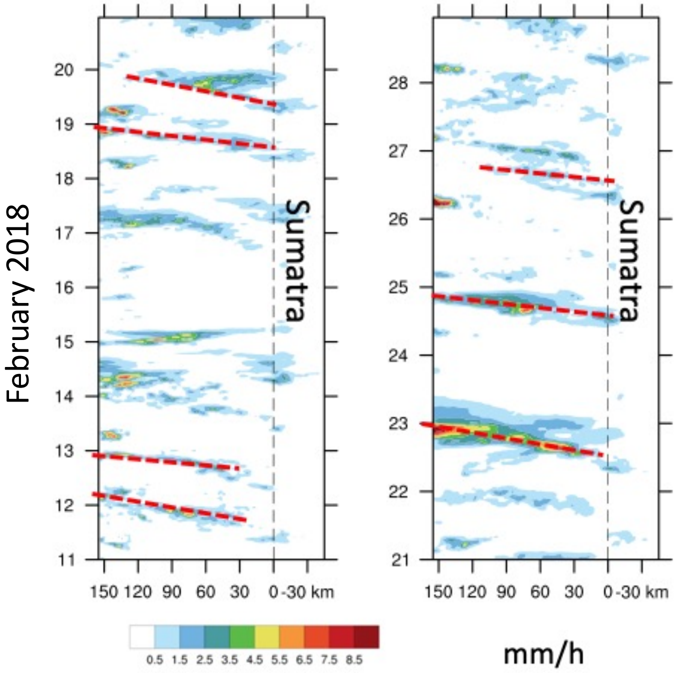
Nocturnal offshore rainfall propagation from Padang

- Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) surface winds and C-band (5-cm) radar rain rates for 2018 at Padang (1 km, 10 min)
- ERA5 winds, divergence and temperature for 2018 (30 km, 1h)



Padang radar loop:

https://drive.google.com/drive/folders/114vuaQ2KQzNnhusJzQ1yG_KjQW28sgVb



Two criteria to identify offshore rainfall propagation:

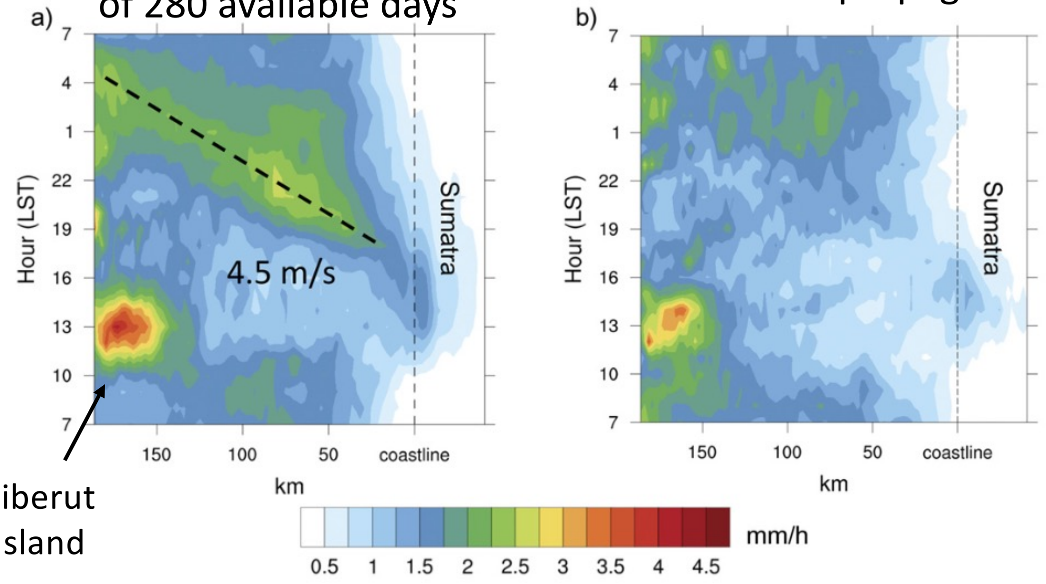
1. Rainfall propagation must be clear, continuous and offshore
2. Offshore propagation must start after 14 LT near the coastline of Padang to ensure that the propagation is nocturnal

Bai et al. (2021)

Nocturnal offshore rainfall propagation from Padang

117 offshore events out of 280 available days

No offshore propagation

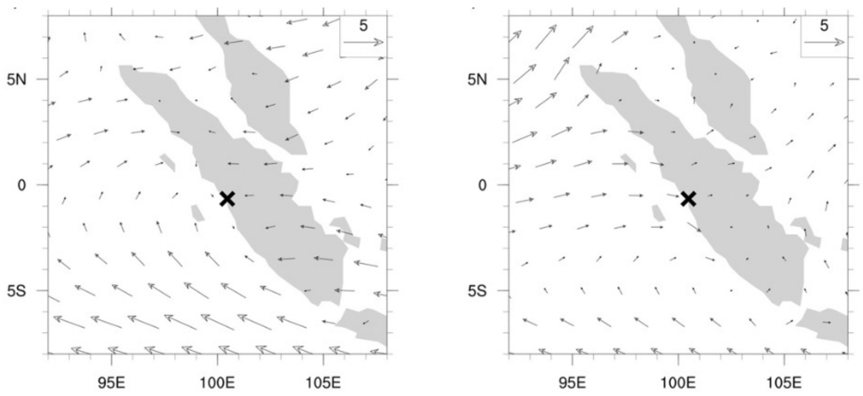


Siberut Island

- Offshore rain events occur 40% of the time
- Mean propagation speed of 4.5 m/s (more consistent with land breeze convergence than gravity waves)

Offshore events

No offshore propagation

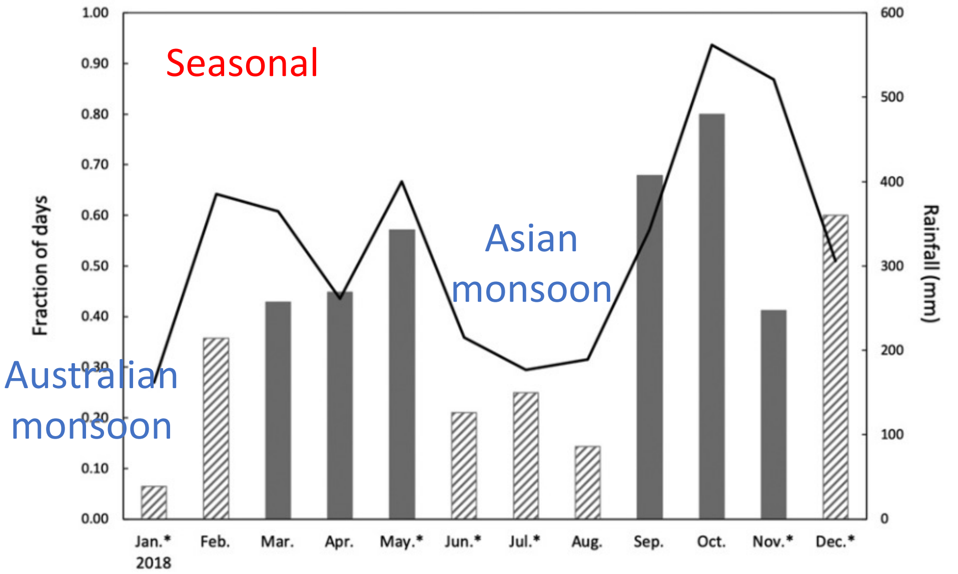


- Events occur on days with weaker onshore flow (i.e., strong onshore flow appears to overwhelm land breeze and ability of convection to propagate offshore)

Bai et al. (2021)

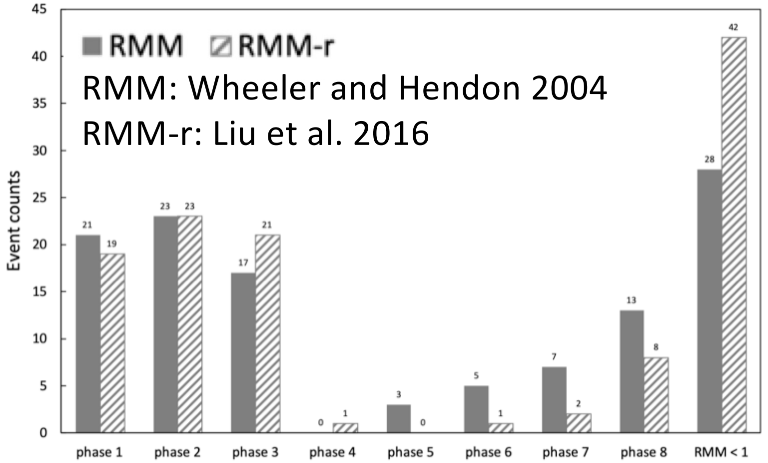
Nocturnal offshore rainfall propagation from Padang

Offshore event occurrence and Padang airport rainfall



- MAM and SON have highest frequency of offshore rainfall propagation (i.e., during monsoon transition seasons)
- Occurrence of offshore events correlated with amount of rainfall received on land as well as weaker onshore winds in MAM and SON

Intraseasonal

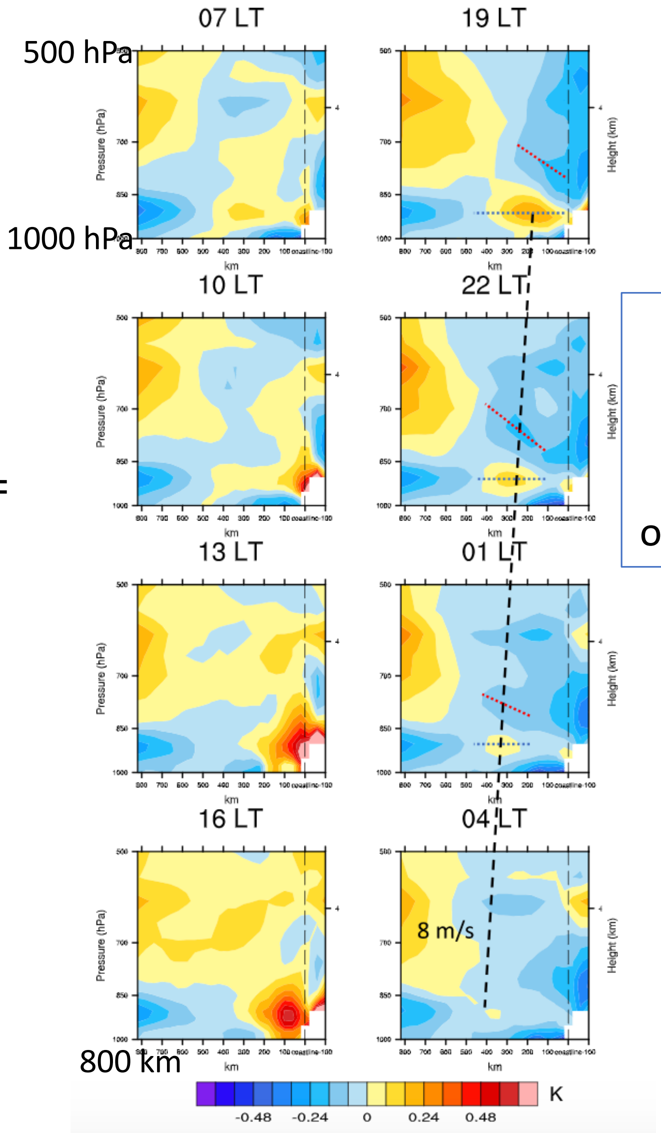


- Most offshore events take place during phases 1-3 when MJO is active in Indian Ocean, or when MJO is weak
- Almost no offshore propagating events occur in phases 4-5, when MJO is active over the MC
- Strong westerly low-level winds prevent land convection from propagating offshore during the active MJO

Bai et al. (2021)

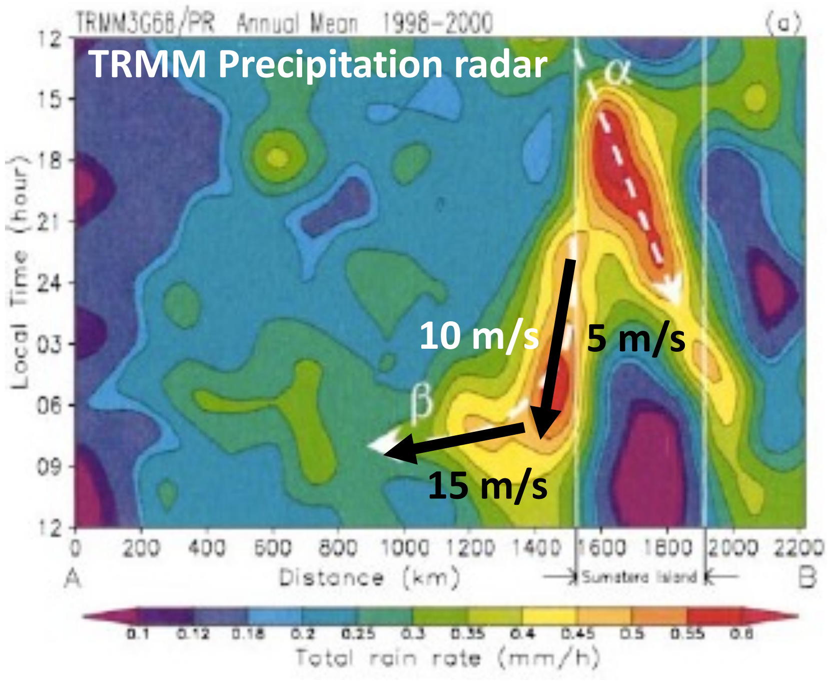
Gravity waves from Padang

- Temperature disturbance propagates faster than the propagation of rainfall and low-level convergence
- Theoretical gravity wave phase speed $c = \frac{N\lambda}{2\pi}$ ~ 6.5-8.5 m/s
- Temperature anomalies by gravity wave can destabilize the environment at night, especially beyond 180 km

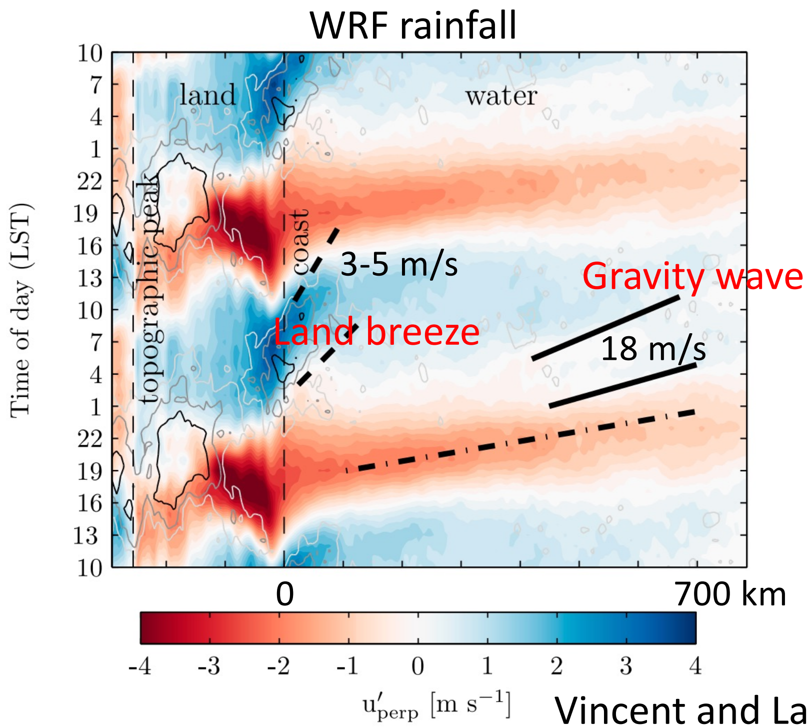


ERA5 2018 temperature anomalies during the offshore events

Offshore rainfall propagation at different distances



Mori et al. (2004)

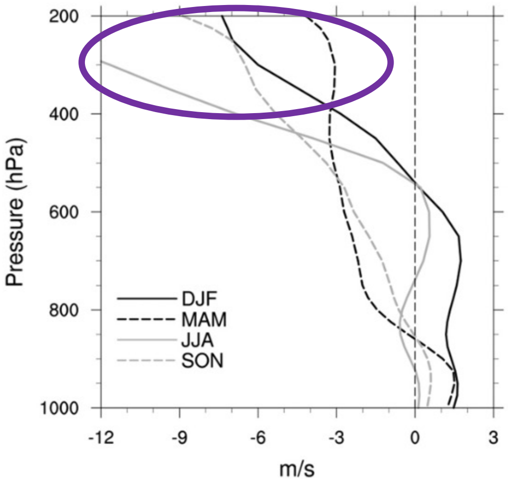


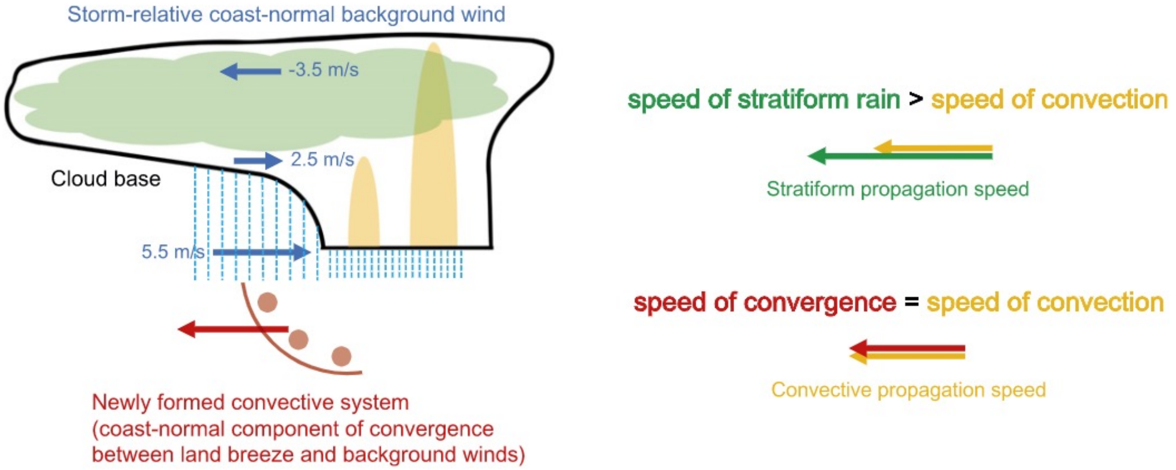
Vincent and Lane (2016)

- Rainfall maxima over coastal oceans propagate faster farther offshore
- Driver for offshore rainfall at different distances may be different

Variations in offshore propagation speed

Coast-normal nocturnal wind



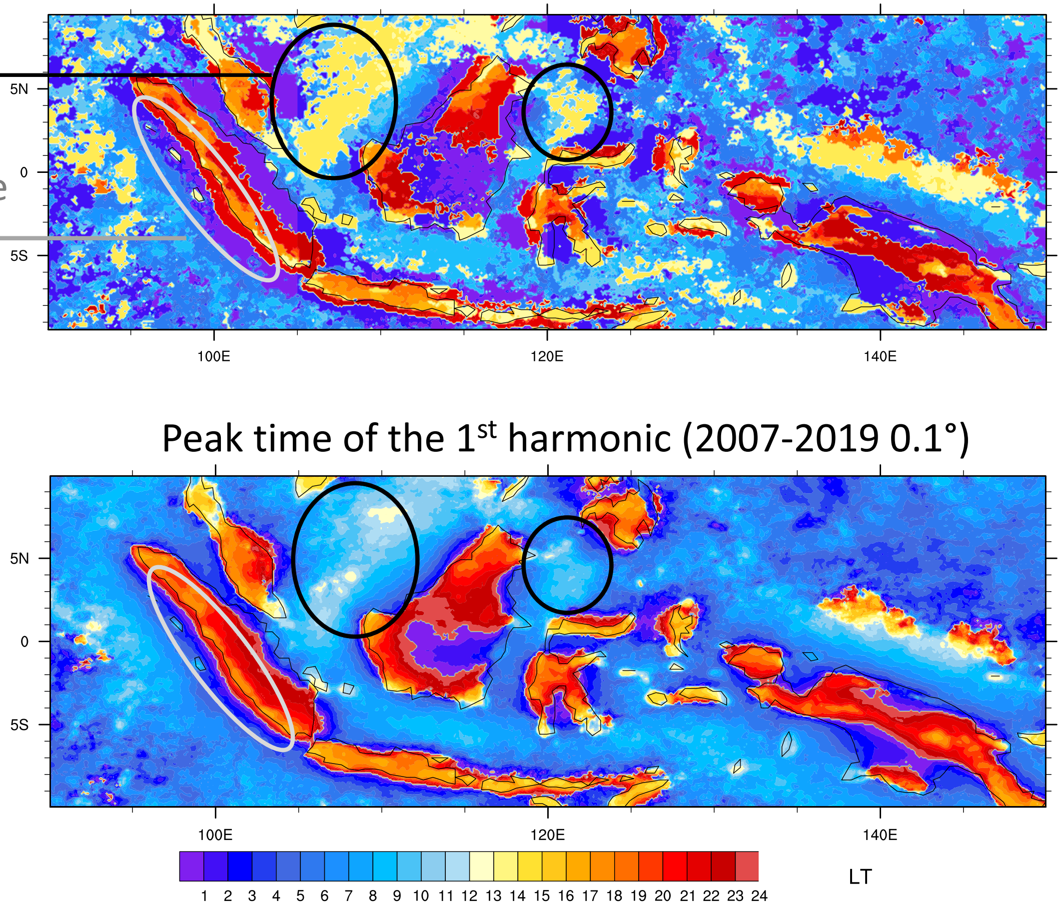


	Total	DJF	MAM	JJA	SON
No. of events	**117**	18	37	12	50
Total rain	**4.5**	4.5	4.0	5.5	5.0
Convective rain	**4.5**	4.5	4.0	5.5	5.0
Stratiform rain	**6.0**	6.5	4.5	10.0	6.5
ERA5 975-hPa convergence	**5.5**	5.5	6.0	5.0	5.5

- Seasonal change in upper-level winds correlated with change in stratiform rain speed
- Storm-relative wind profile leads to stratiform clouds expanding ahead of convective clouds (consistent with Parker and Johnson 2000), explaining part of the satellite discrepancy

Daily maximum *vs.* 1st harmonic

- Defining the diurnal rainfall by maximum rain rate gives different timing than the first harmonic across the MC



Time of maximum hourly rain (2007-2019 0.1°)

Over interior seas rainfall peaks later than the 1st harmonic

Mountainous & offshore rainfall peaks earlier than the 1st harmonic

Peak time of the 1st harmonic (2007-2019 0.1°)

e.g., Yang and Slingo 2001;
Nesbitt and Zipser 2002;
Peatman et al. 2014;
Birch et al. 2016

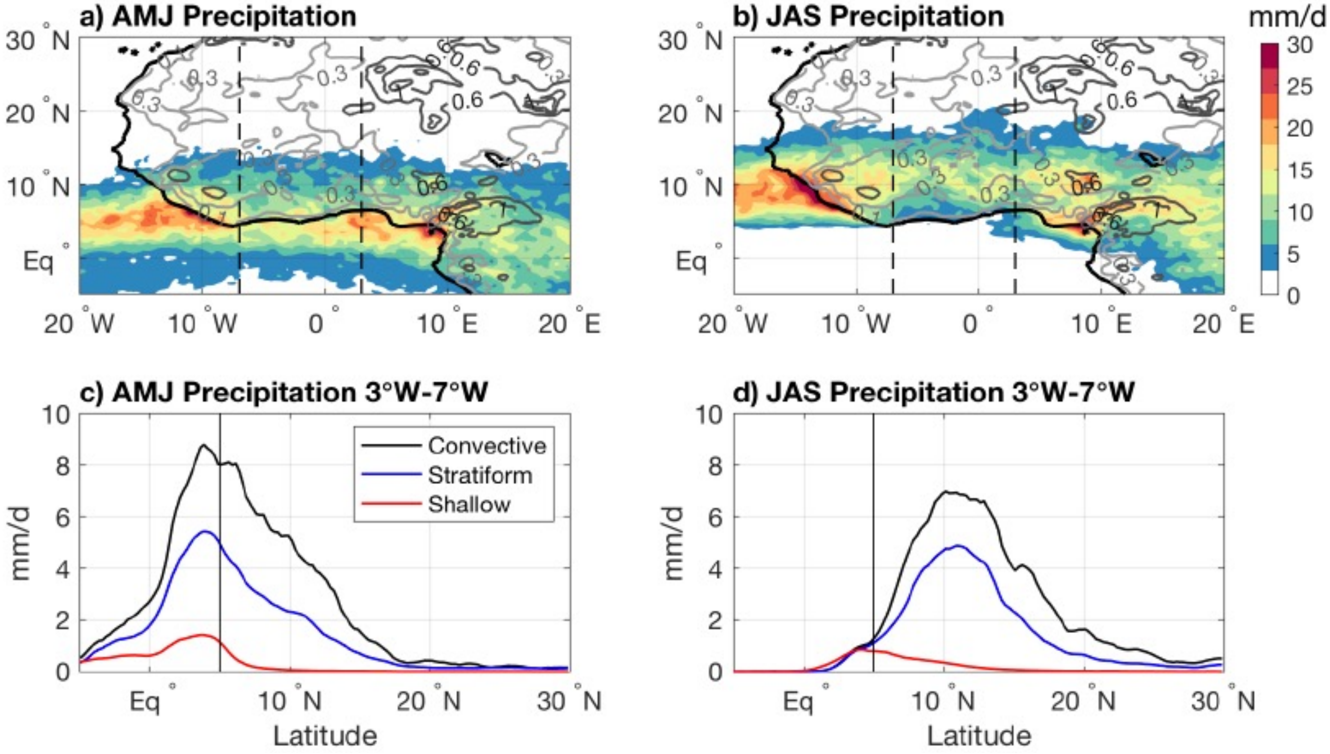
West African coastal processes

April-June (pre-monsoon)

June-September (monsoon)

PR/DPR (1998-2019)

PR/DPR



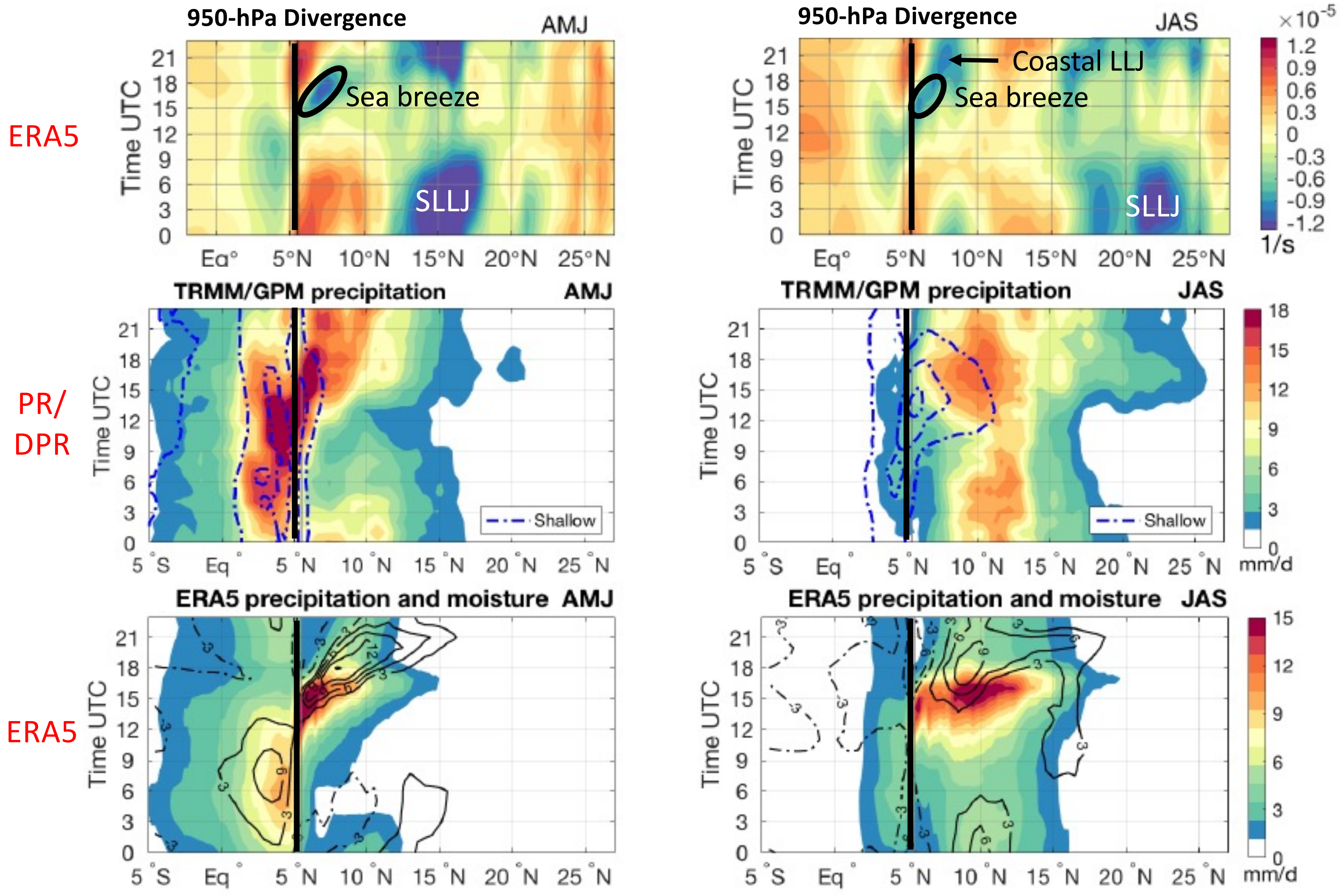
- Rain maximizes south of coast during pre-monsoon

- Shallow convective rain intrudes inland during monsoon

Huaman et al. (2023)

April-June (pre-monsoon)

June-September (monsoon)



- Sea breeze stronger in pre-monsoon
- Nocturnal coastal LLJ present during monsoon
- No obvious land breeze

- Strongest rain with sea breeze in pre-monsoon
- Nocturnal rain during monsoon assisted by moisture from coastal LLJ

- ERA5 vertically-integrated moisture flux convergence (contours) consistent with PR/DPR diurnal rain evolution, but ERA5 precip is not!

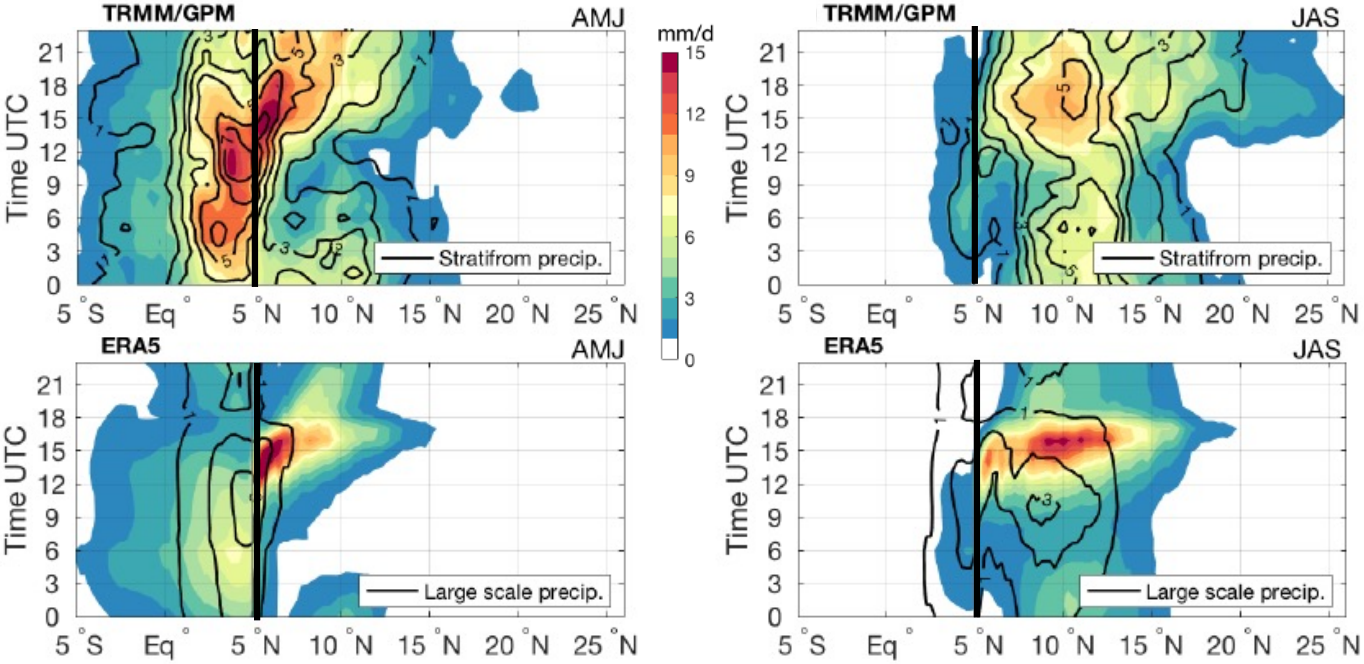
Huaman et al. (2023)

April-June (pre-monsoon)

June-September (monsoon)

PR/ DPR

ERA5



Diurnal precipitation types

- Radar-observed convective (shaded) and stratiform (contours) rain occur simultaneously, suggesting strong mesoscale convective organization in both seasons

So, please use reanalysis rain with great caution (esp. in regions where precipitation is not assimilated), but dynamical fields seem reasonable in this case.

ERA5 rain over land:

- Convective rain occurs too early and is overly intense (a common GCM problem linked to the convective parameterization), weak to no propagation
- Large-scale rain (which is from resolved/grid-scale microphysics) is absent in AMJ and disconnected from convective rain in JAS (e.g., maximizes at 10 am when radar rain is minimum)

Huaman et al. (2023)

Time to enjoy some Italian coastal processes!