Gravity waves and the diurnal cycle of tropical convection

Todd Lane

School of Earth Sciences, The University of Melbourne

ARC Centre of Excellence for Climate System Science (ARCCSS)

Collaborators/Coauthors: ***Claire Vincent*** *(U. Melb., ARCCSS),* ***Muhammad Hassim*** *(CCRS Singapore),* ***Wojciech Grabowski*** *(NCAR)*

SPARC Gravity Wave Symposium
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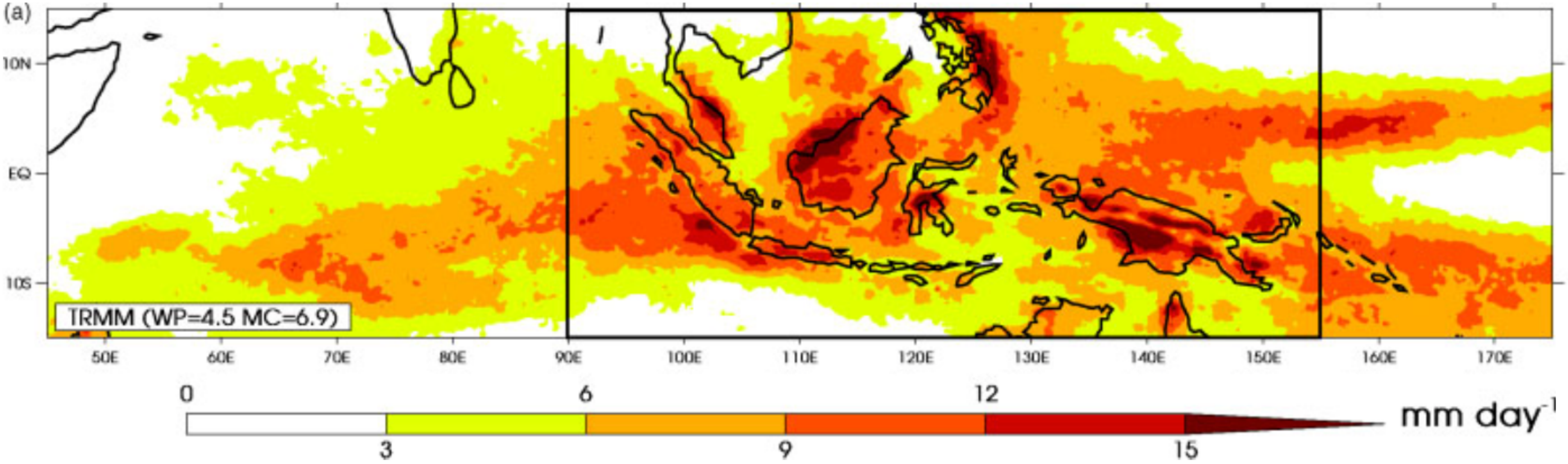
The Maritime Continent

TRMM Rainfall (2008-2009 DJF)



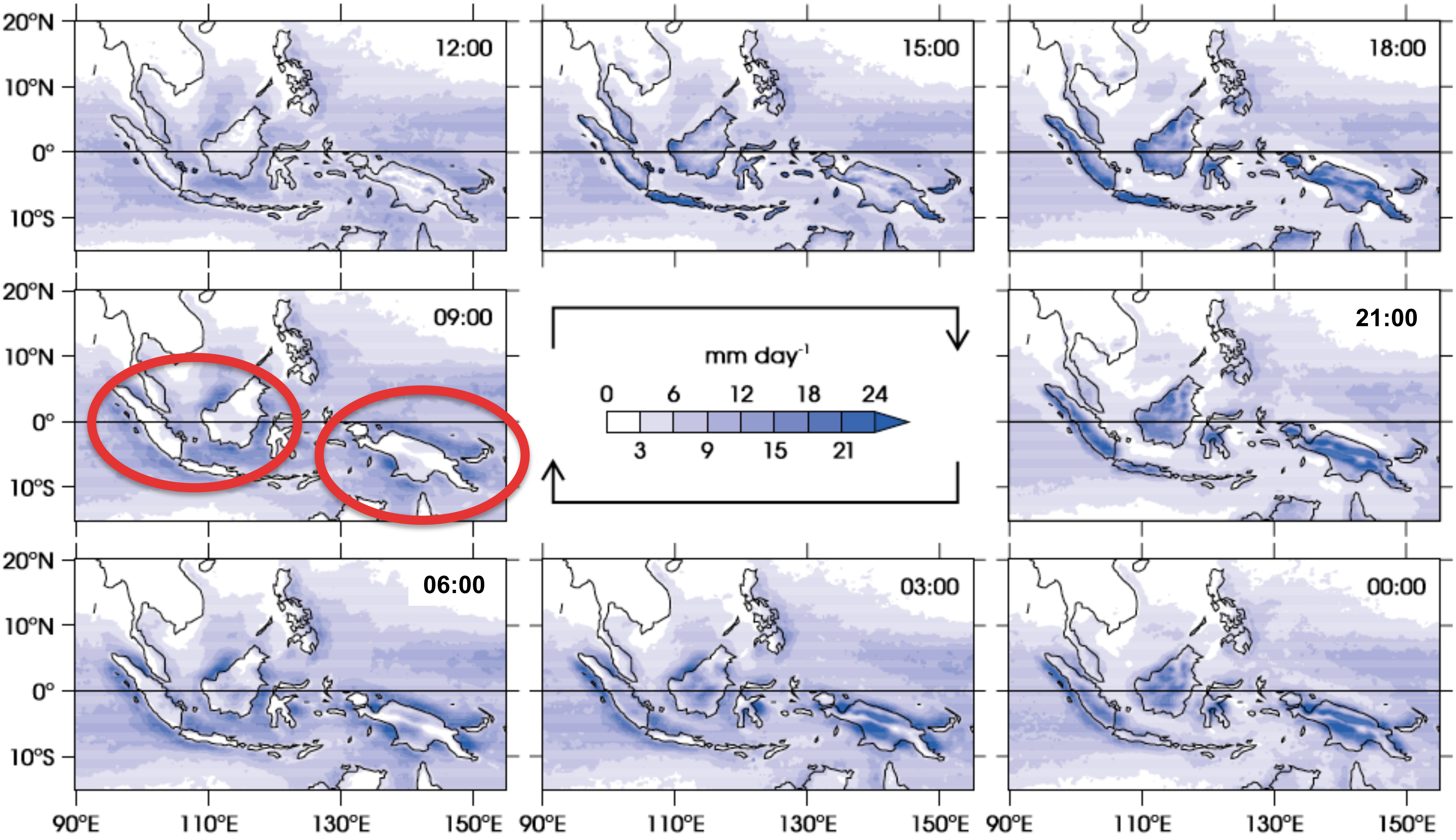
Love et al. 2011 (QJRMS)

Region characterized by strong:

- Regional precipitation
- Land-sea contrast in precipitation with notable diurnal cycle
- Coastal and orographic influences on convection and rainfall
- Influence from large-scale modes of variability (e.g., MJO) and vice-versa

Location of notable errors in all classes of weather and climate models

November-April Diurnal Cycle (LT) of Precipitation from TRMM



[3B42HQ, 1998-2012]

Peatman et al. (2014, QJRMS)

Motivation…

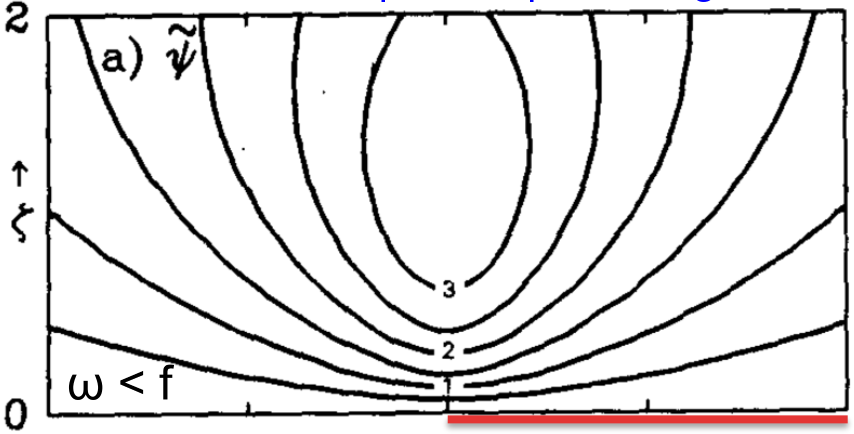
- **What are the key processes controlling the diurnal cycle over the Maritime Continent?**
- **What causes the offshore rainfall maximum?**
  - **Occurs beyond extent of land breeze**
  - **Leading explanation is diurnally forced gravity waves**
    - **Discussed in detail by Yang and Slingo 2001, Mapes et al 2003, Love et al. 2011, Qian et al. 2012, and others**

Hassim, M. E. E., T.P. Lane, and W.W. Grabowski, 2016: The diurnal cycle of rainfall over New Guinea in convection-permitting WRF simulations, *Atmos. Chem. Phys.*, **16**, 161-175, doi:10.5194/acp-16-161-2016.

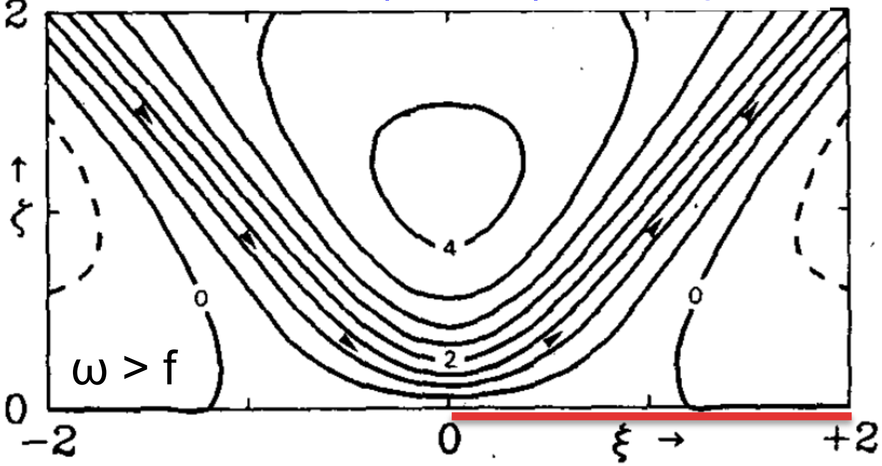
Vincent, C.L., and T.P. Lane, 2016: Evolution of the diurnal precipitation cycle with the passage of a Madden-Julian Oscillation event through the Maritime Continent. *Monthly Weather Review*, **144**, 1983-2005.

Rotunno (1983) – *On the linear theory of the land and sea breeze*

Streamfunction |latitude| > 30 degrees



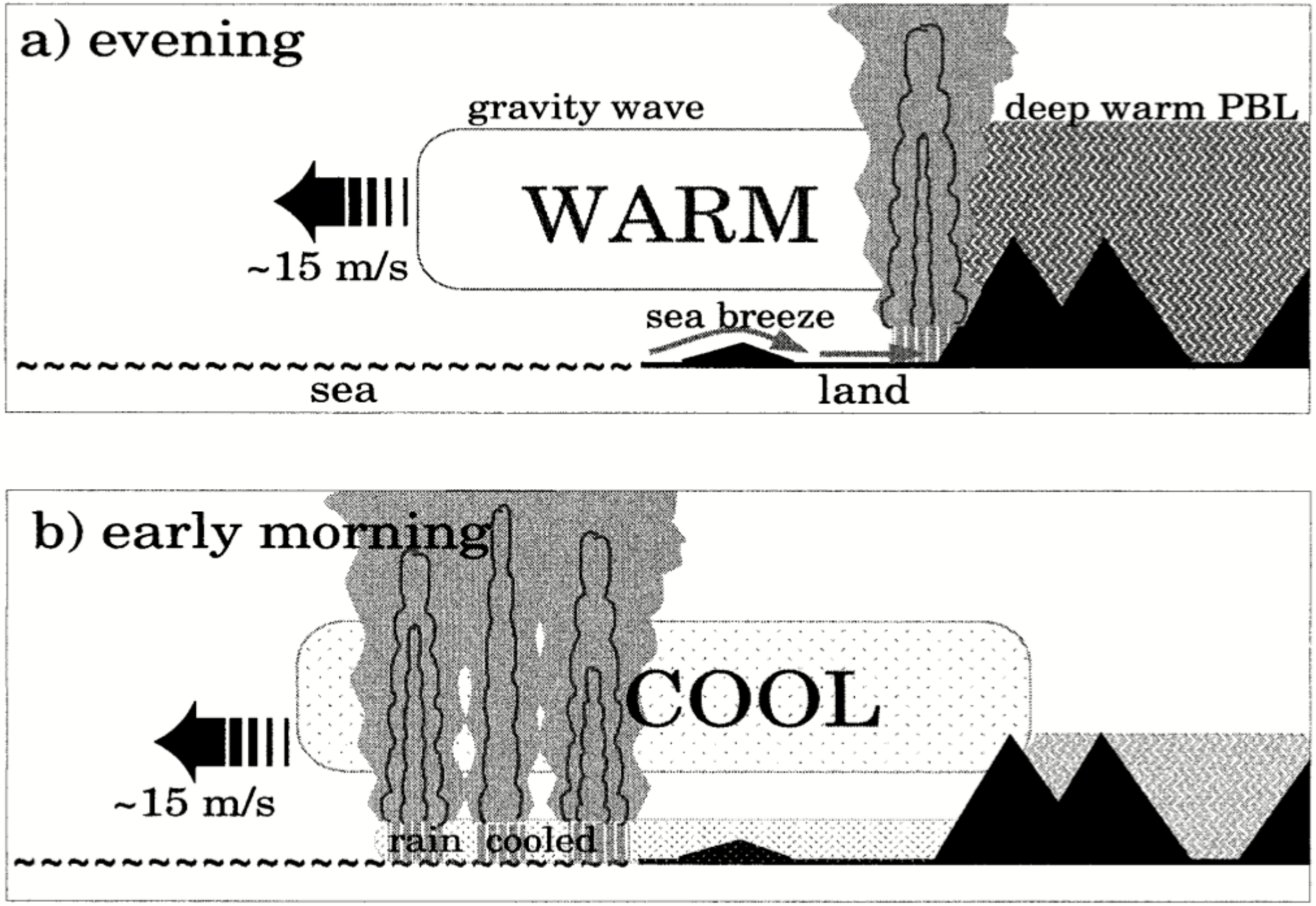
Streamfunction |latitude| < 30 degrees



Fundamentally different behaviors of idealized sea/land breezes poleward or equatorward of 30 degrees longitude

- ω < f or ω > f , ω=2π/(24h)
  - **Mid-latitudes – coastally confined**
  - **Tropics – inertia-gravity waves**
- Tropical regions support inertia-gravity waves with diurnal (intrinsic) periods.
- Other important results
  - Significant phase differences between tropical / midlatitude cases
  - Differences reduce with friction
  - Variations with wind (Qian et al. 2010).
  - See also Du and Rotunno (2015)

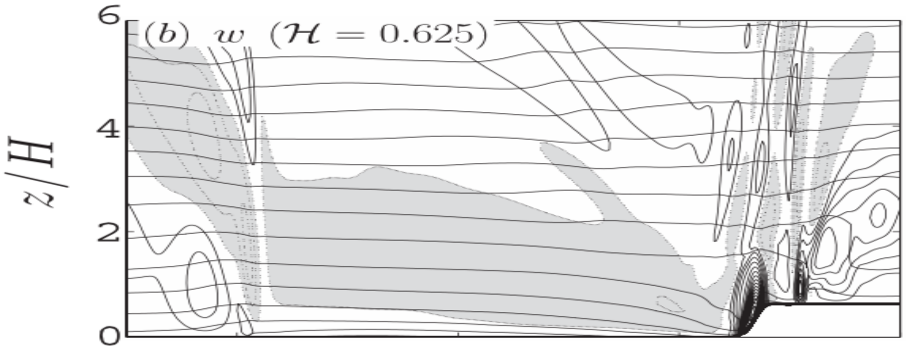
Mapes et al. 2003 – *Diurnal Patterns of Rainfall in Northwestern South America. Part III: Diurnal Gravity Waves and Nocturnal Convection Offshore*



Suggested the formation of offshore precipitating convection was related to destabilisation by diurnal gravity waves generated by the diurnally varying elevated mixed layer over mountainous terrain

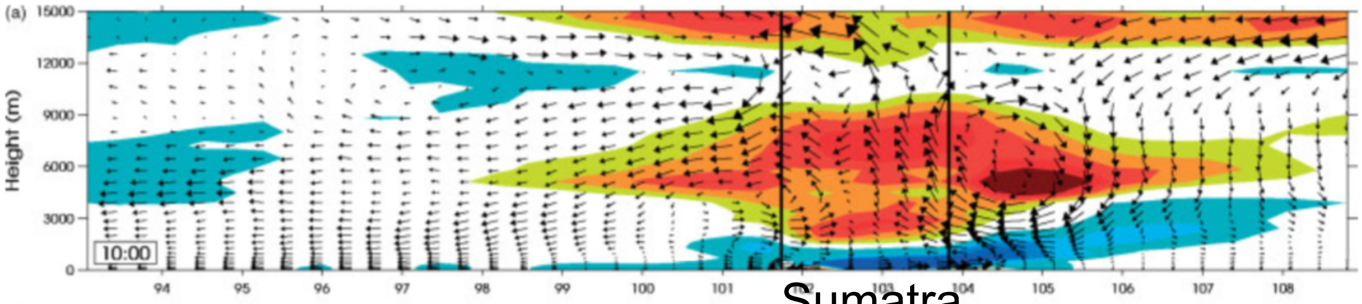
Qian et al. 2012 - *Topographic Effects on the Tropical Land and Sea Breeze*

- Linear and nonlinear idealized calculations
- Found no significant offshore effect for linear cases
- Largest offshore impact came from strengthening of the land breeze (**nonlinear frontal propagation instead of wave effects**)



Love et al. 2011 - *The diurnal cycle of precipitation over the Maritime Continent in a high-resolution atmospheric model*

- Used convection-permitting simulations to examine offshore precip. in Maritime Continent
- Identified possible **role of 'stratiform heating' from convection in generating diurnal waves**.



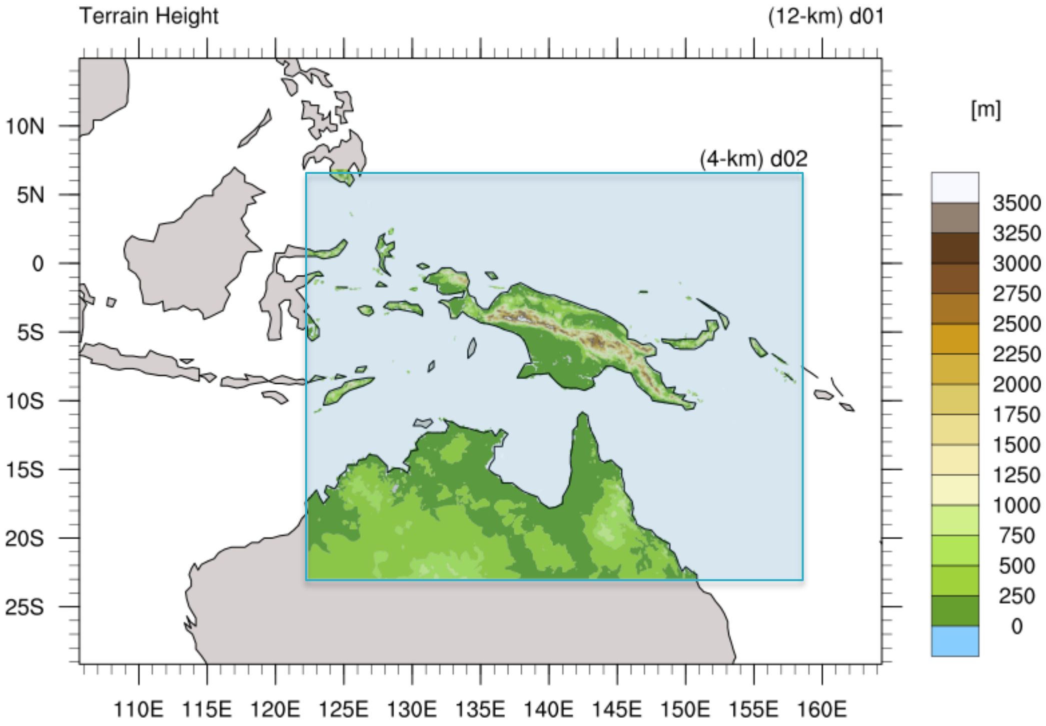
Sumatra

Key Questions:

How important are diurnal gravity waves in forming / promoting / initiating convection offshore?

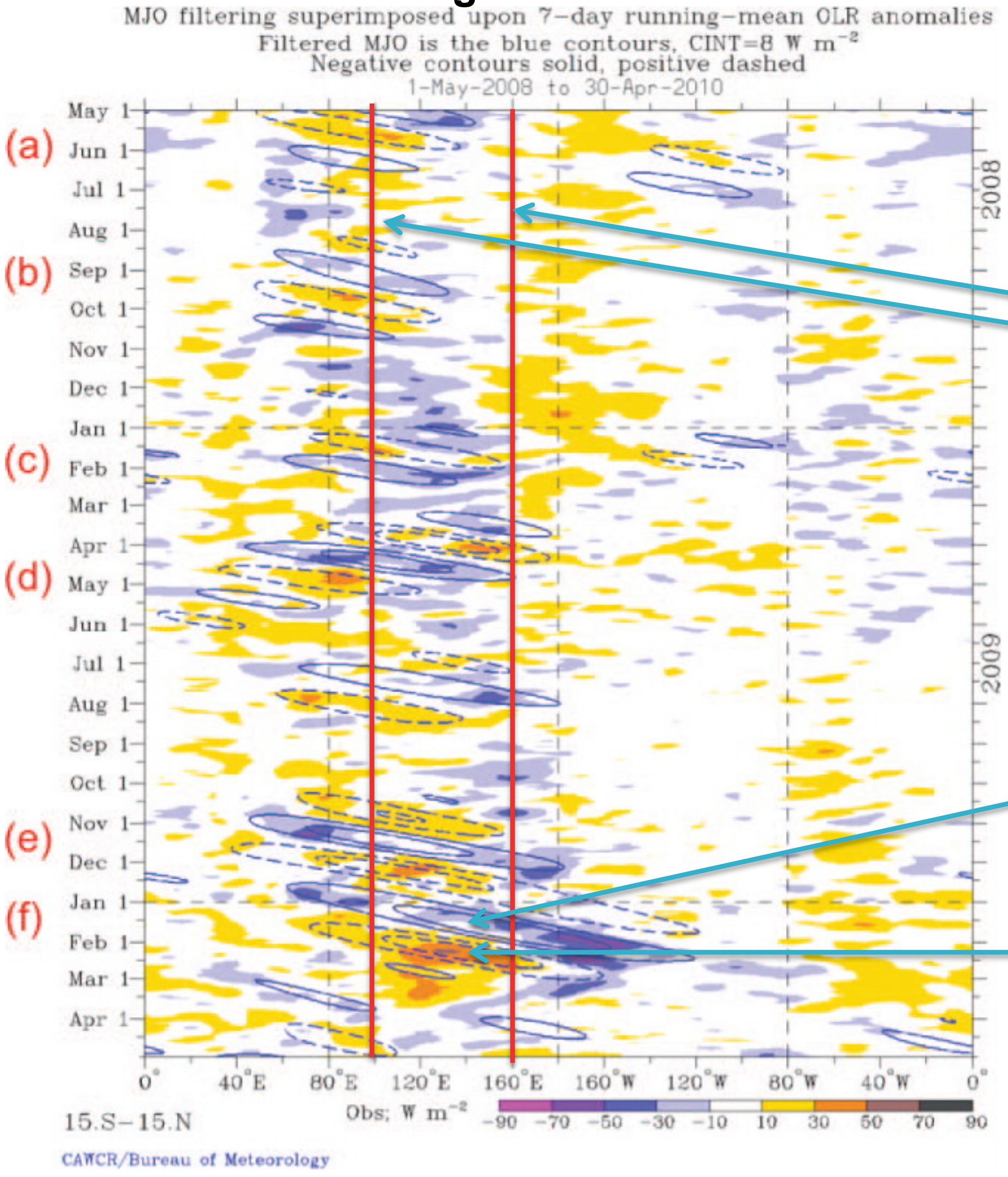
What is the role of topographic heating (dry convection) versus moist convection in generating these diurnal waves?

WRF Model simulations



- Explicit convection on 4 km grid
- Initial and boundary conditions (for 12 km grid) from ERA-Interim
- Simulation for one month (free-running and re-initialized produce similar results)
- Higher resolution domain (1.33 km) over shorter period produced similar results

OLR anomalies during YOTC – Filtered Madden Julian Oscillation (MJO)



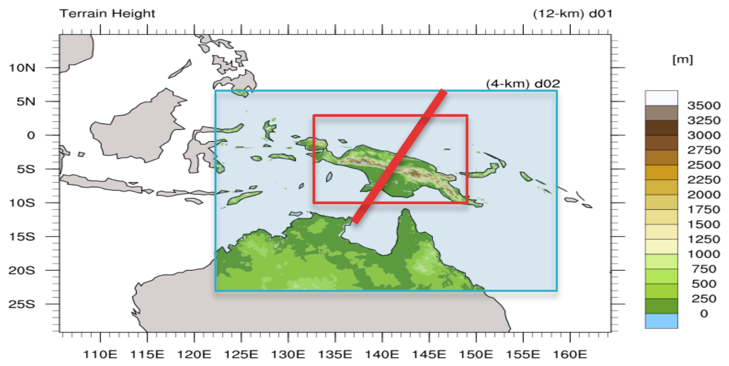
Maritime Continent

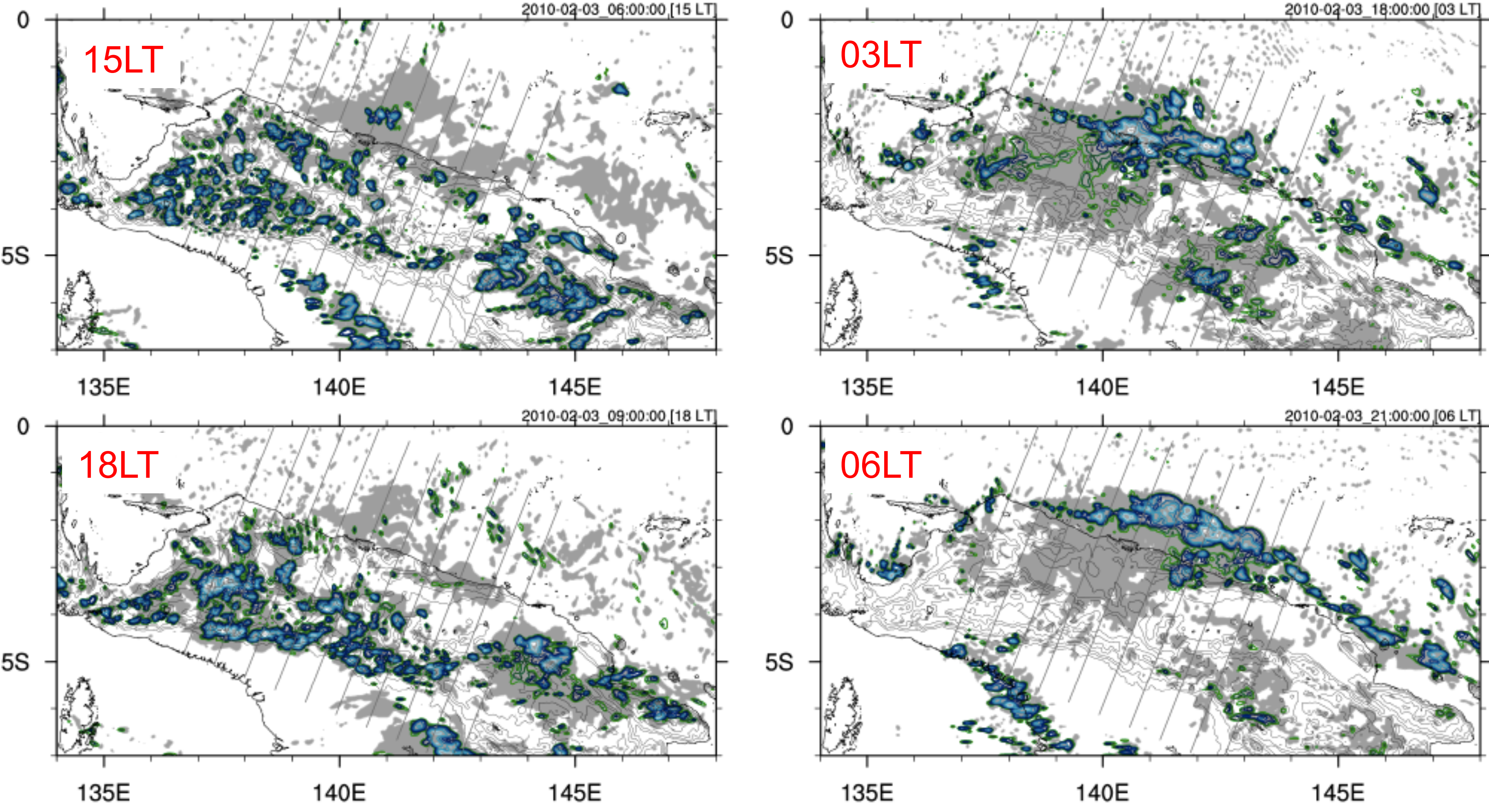
Jan 2010
(active MJO)

Feb 2010
(suppressed MJO)

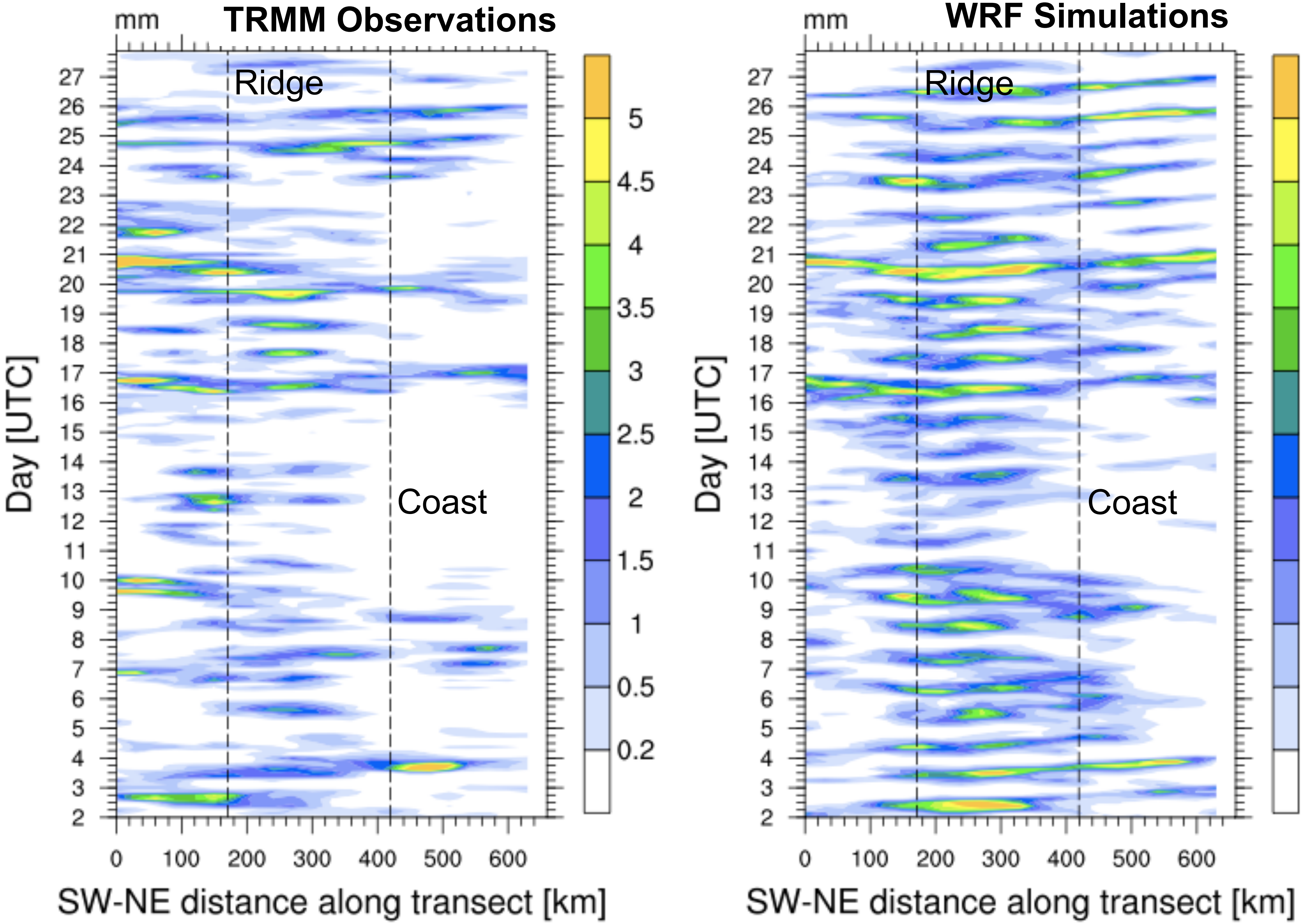
Waliser et al. (2012, BAMS)

Example of diurnal evolution of simulated convective systems (3 Feb 2010)



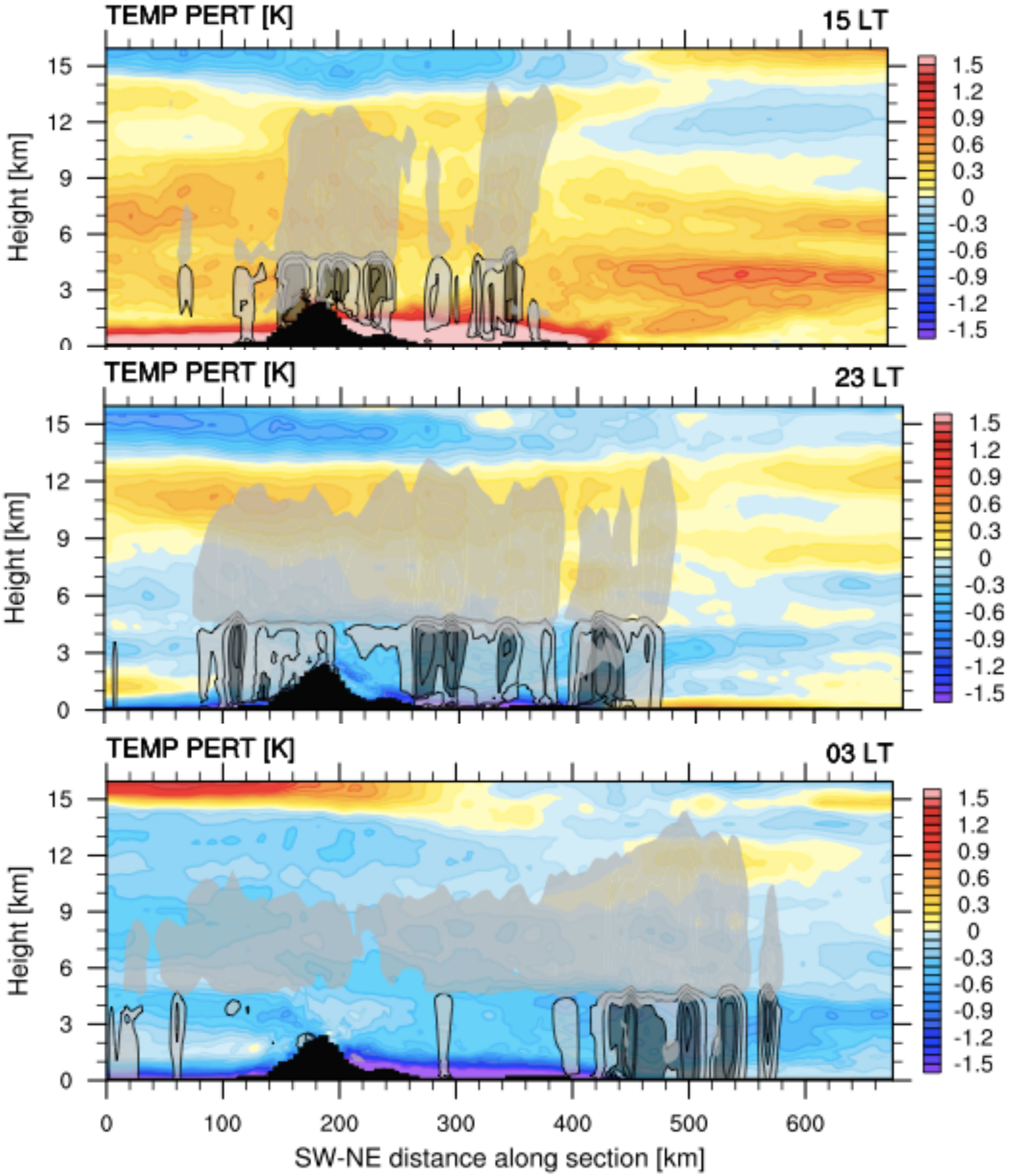


RAINFALL: 1 – 28 February 2010

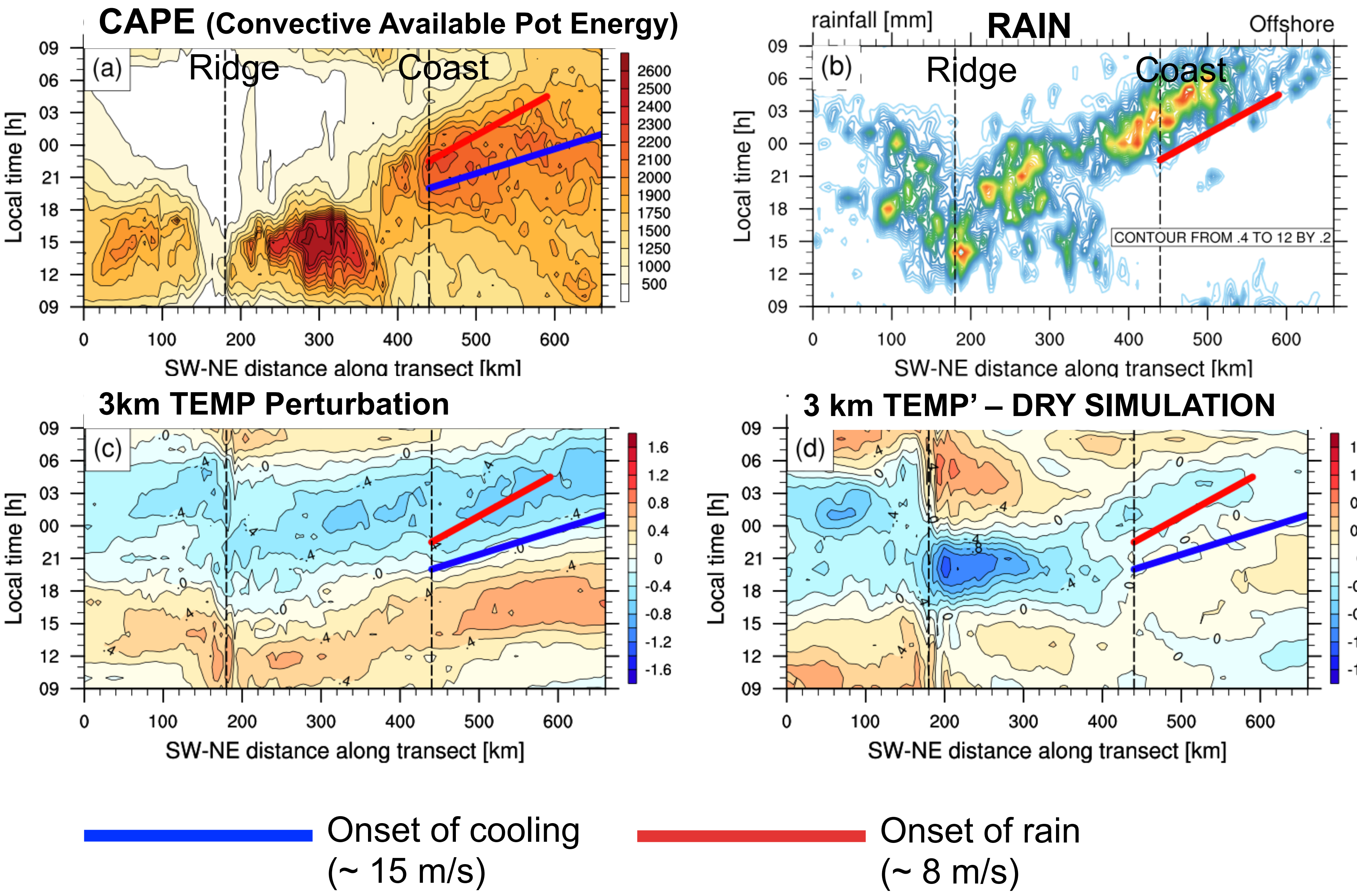

TRMM Observations

WRF Simulations

Temperature perturbations (from diurnal mean)
Composite – days with offshore propagation

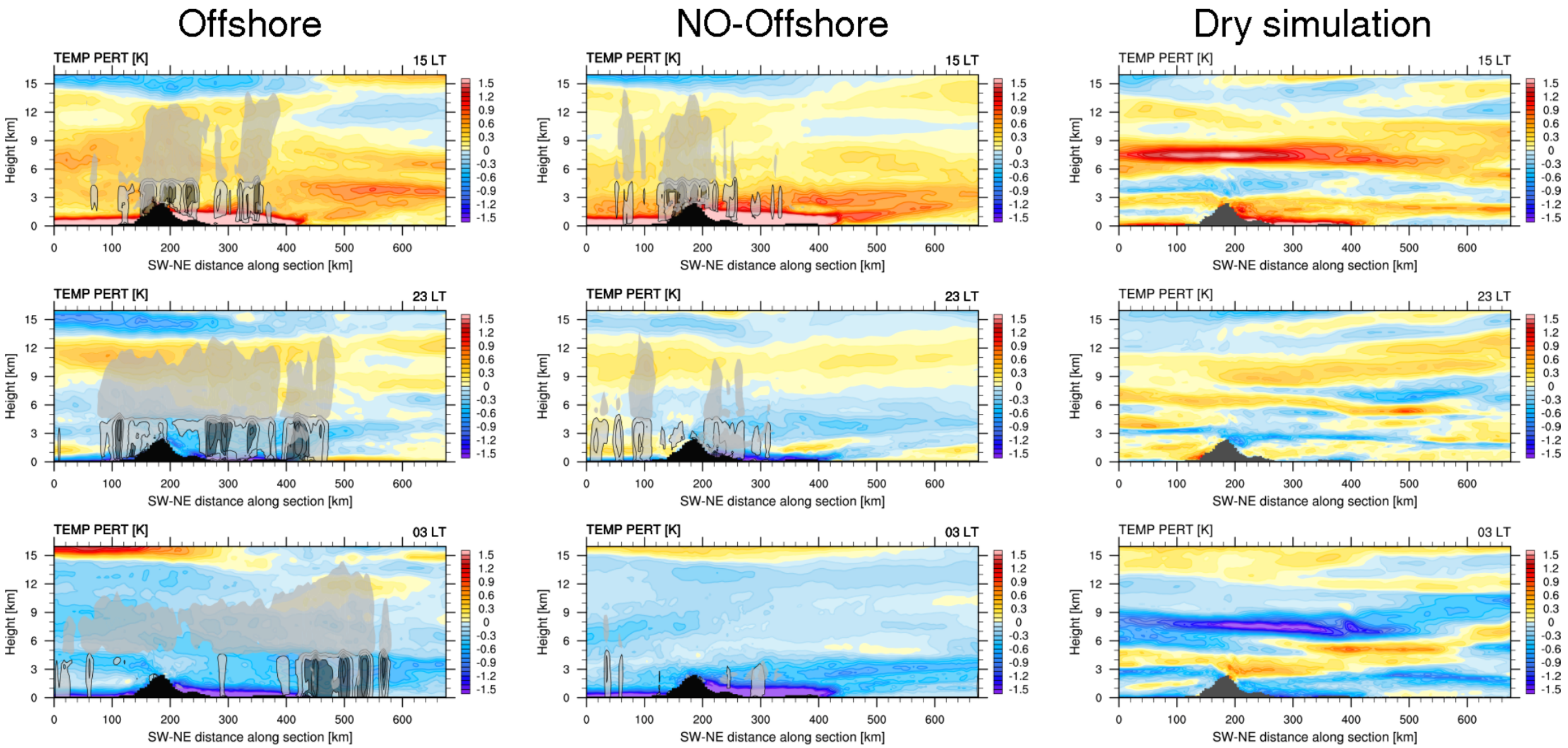


Composite: Days with offshore propagation



🟦 Onset of cooling
(~ 15 m/s)

🟥 Onset of rain
(~ 8 m/s)

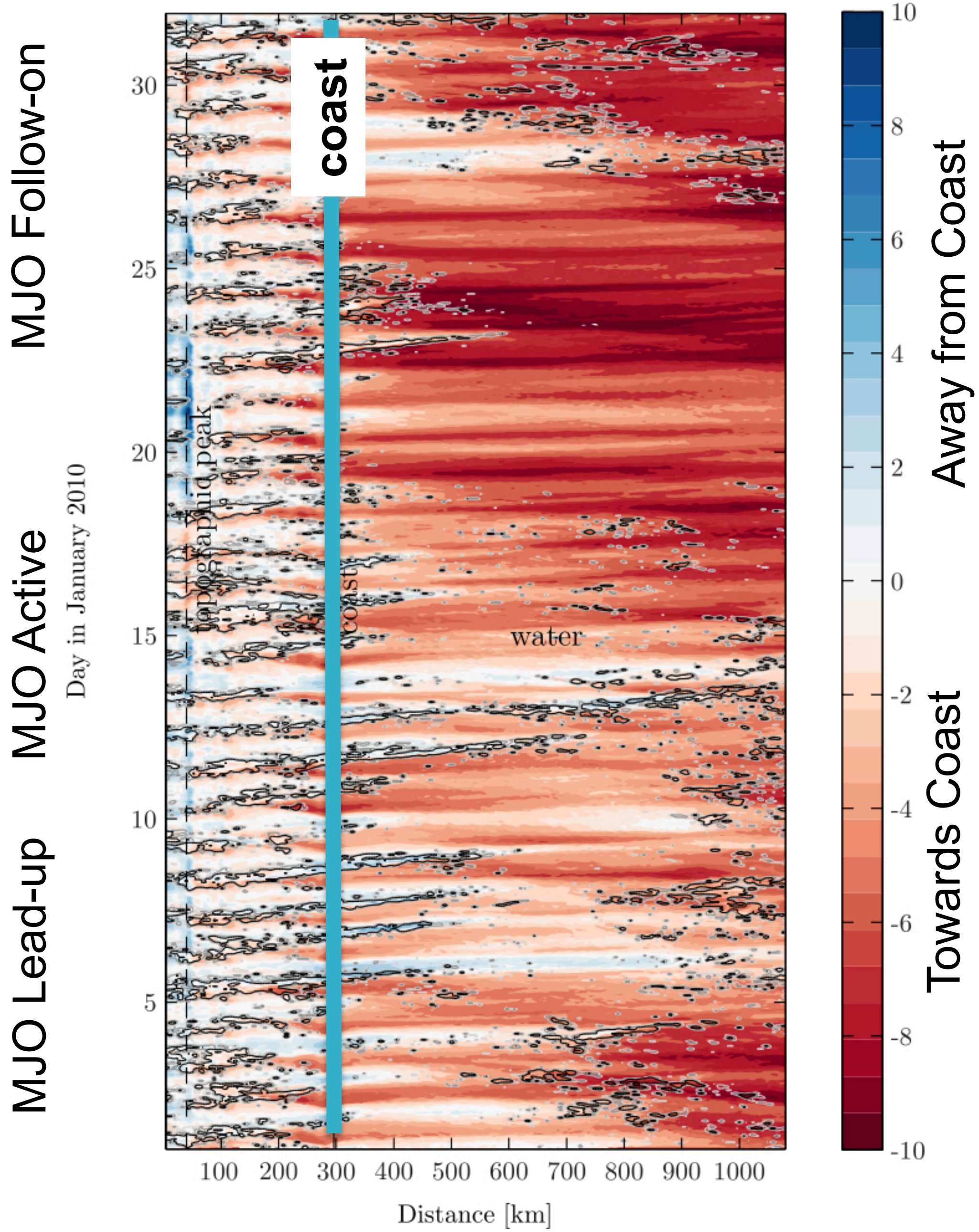


Speed of offshore-propagating cool anomaly (in full physics simulations) consistent with n≈3 gravity wave.

Similar offshore wave dynamics for NO-Offshore days. Lack of convection closely related to background moisture (more stable and drier at mid-levels on NO-Offshore days)

Dry simulation shows wave response with smaller vertical wavelength, consistent with shallower (dry) forcing and slower propagation speed.

JANUARY 2010 (WRF Results)
wind perpendicular to New Guinea & Rain

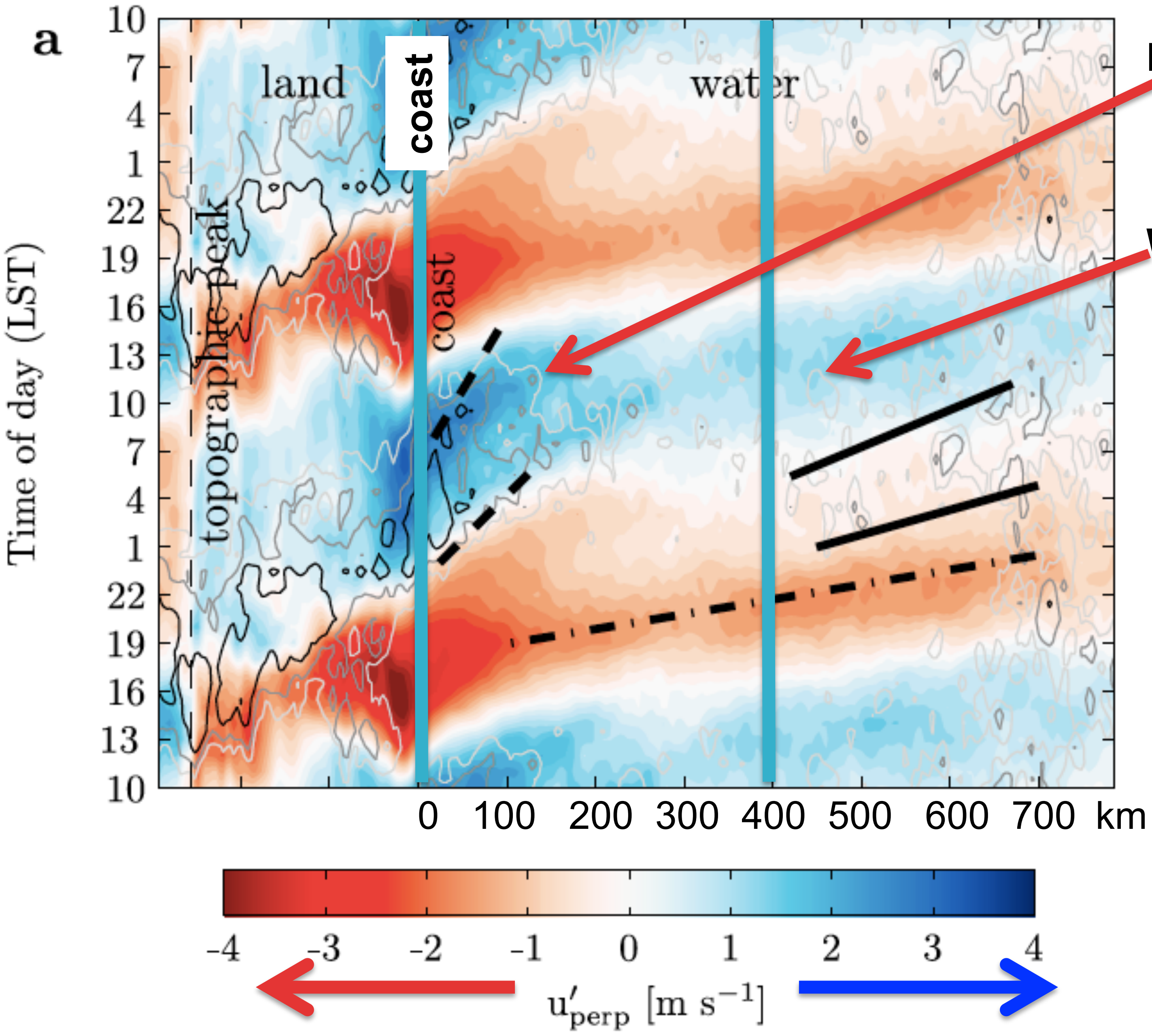


- Gravity wave induced wind perturbations extend up to 800 km offshore

- More far-offshore rainfall during lead-up and active phases of MJO.
  - Related to mid-level moisture

- **Evidence of modulation of far-offshore (> 700 km) rainfall by gravity waves**
  - **Esp. in lead-up and active phases**

Composite wind perturbations @ 80m (5-17 JAN 2010)

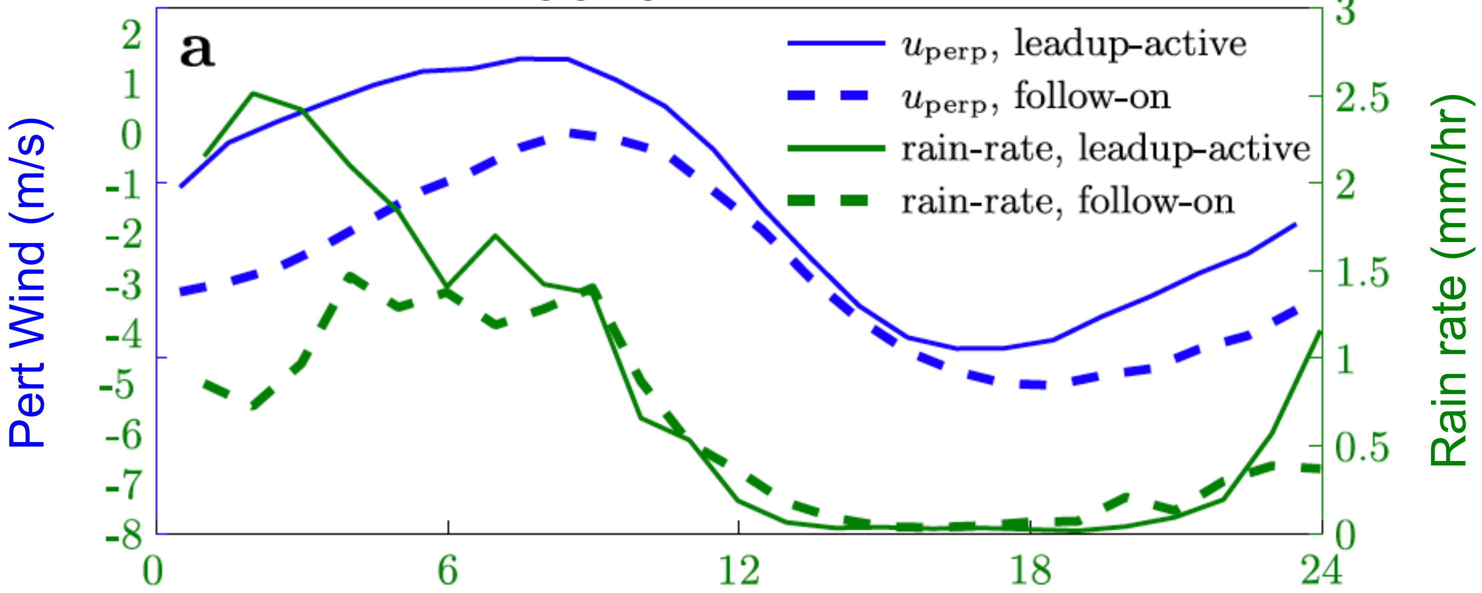


Extent of land breeze

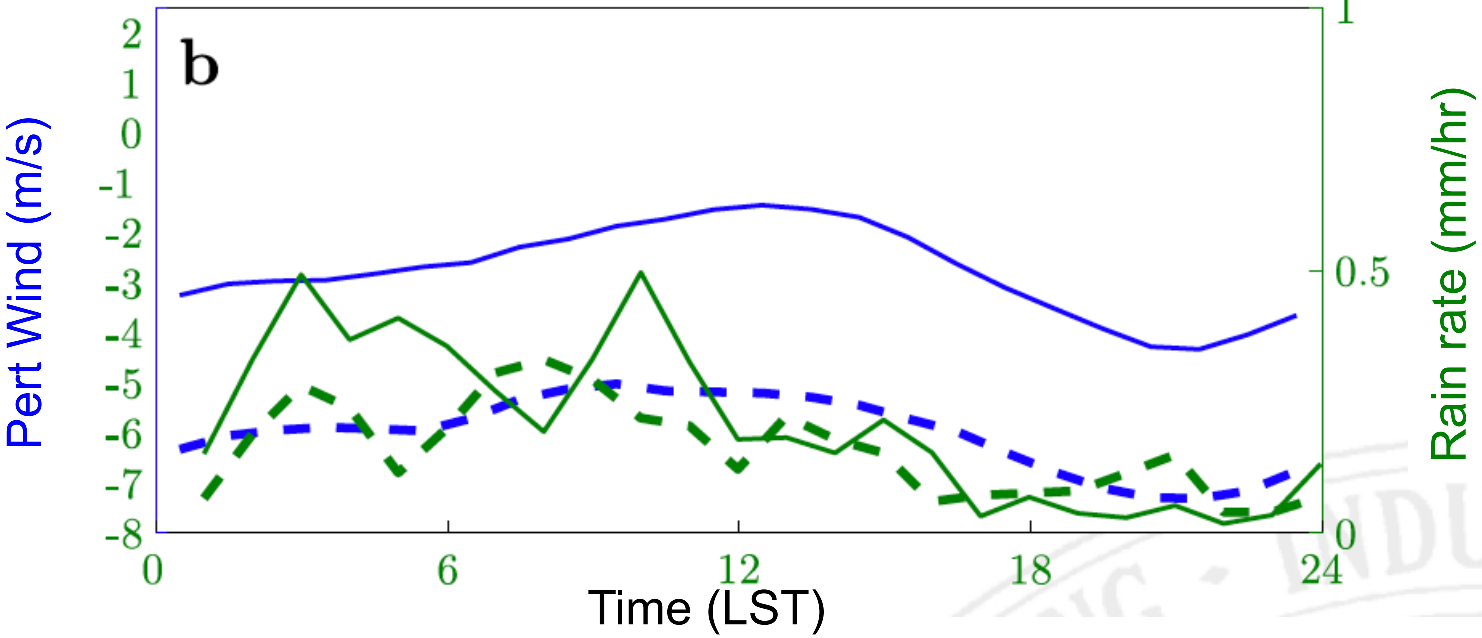
Wave response

JAN 2010 WRF Results

COAST



400 km OFFSHORE



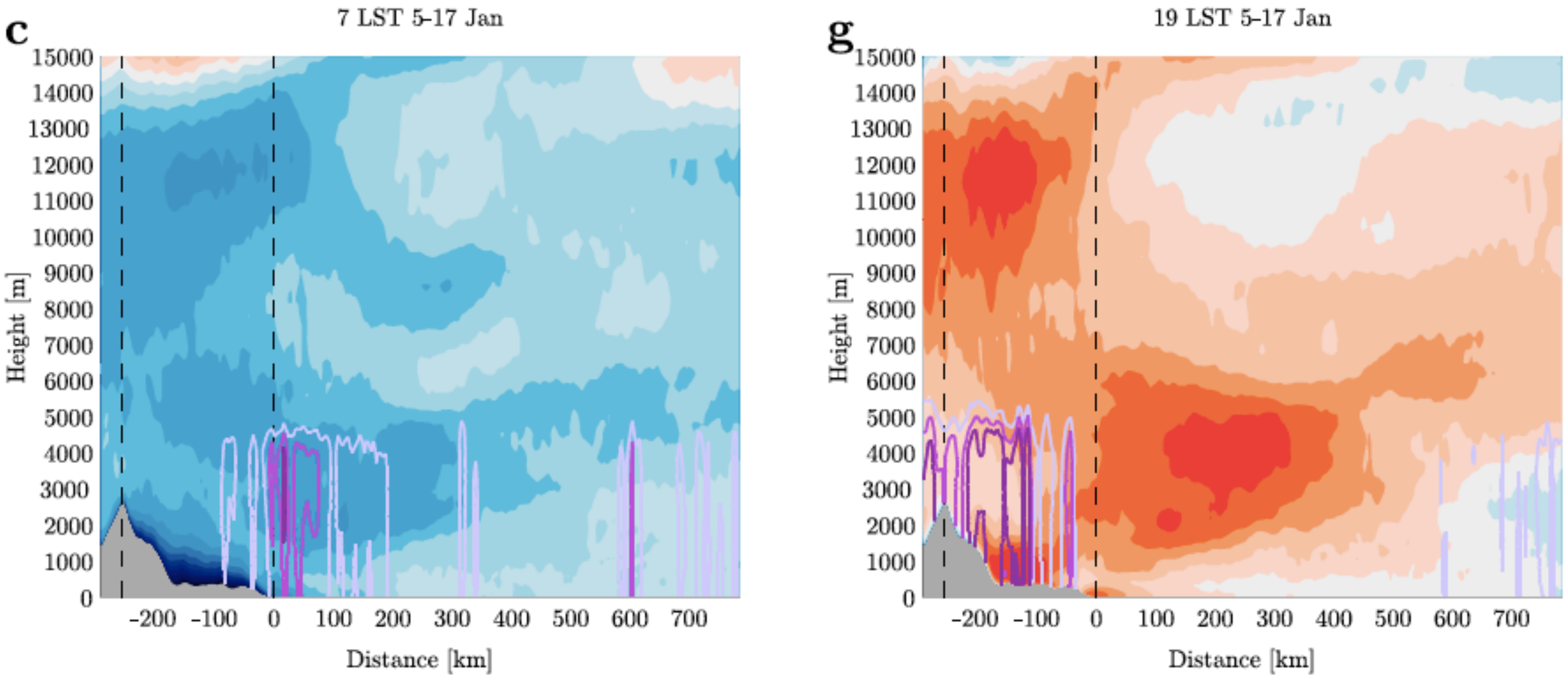
Summary..

Offshore rainfall maximum in maritime continent closely related to diurnal gravity waves

- Convectively-generated diurnal waves (from daytime convection over land) play an important role in the wave generation.
- Near coast – organized convection associated with land breeze propagates into an environment that has been destabilized by the diurnal waves
- Farther offshore (e.g., ~400 km) – waves modulate convection when environment is sufficiently moist (e.g., active MJO).

Future work / outstanding questions:

- Possible that simulated offshore waves are too intense as land-based convection is too strong in model.
  - examine using observations from upcoming YMC campaign
- How do wind variations associated with large-scale (e.g., MJO) affect propagation of these waves?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7 LST 5-17 Jan
g
19 LST 5-17 Jan
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100
200
300
400
500
600
700
Distance [km]