Mesoscale Convective Systems over the rainiest spot on Earth: OTREC field campaign and Cloud-Resolving Simulations

John Mejia[1] and Juan Henao[2]

[1]Desert Research Institute Reno
[2]GIGA

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Abstract

This research study shows the ability of cloud resolving models (CRM) to simulate Mesoscale Convective Systems (MCS) over the far Eastern Pacific region, off the coast of Colombia and Panama. The simulation period coincides with the newly developed OTREC field campaign (August-September, 2019), which provided enhanced upper-air soundings, NSF/NCAR G-V dropsonde and HIAPER Cloud Radar data to help evaluate the model and diagnose the environmental conditions favoring MCS development. We tested the model sensitivity to three different microphysics schemes: two popular bulk schemes (Thomson and Morrison) and one spectral bin (SBM) scheme. The models are diagnosed on their ability to simulate the observed large-scale and mesoscale environments associated with MCSs development, including the ChocoJet and Caribbean low-level jets, the semi-permanent Panama low, vertical shear, and mid-level diurnal gravity waves. We also examined the vertical distribution of hydrometeors concentrations and diabatic heat and cooling profiles. Results show that not only the SBM represents better the spatial and vertical distribution of precipitation, but also simulates better MCSs characteristics (intensity, duration, organization) and their predominant westward movement. We hypothesize that the success of the SBM in producing better organized and more long-lasting MCS stands in the stronger diabatic heating, related to a top-heavier mass profile that helps support upper-level convergence, and more intense low-level diabatic cooling that helps support stronger gravity currents. OTREC observations and CRM results shed light on the role of MCSs in the generation of enhanced mid-level mesoscale vorticity, which has been related to generation of easterly waves or enhancement of existing ones. Although the SBM is unpractical due to its computation cost (fast version takes about 10-12 times longer), it represents an important step forward in cloud modeling, with suggestive results indicating that SBM improves confidence of the physical basis of the elusive and challenging simulation of realistic tropical MCSs.

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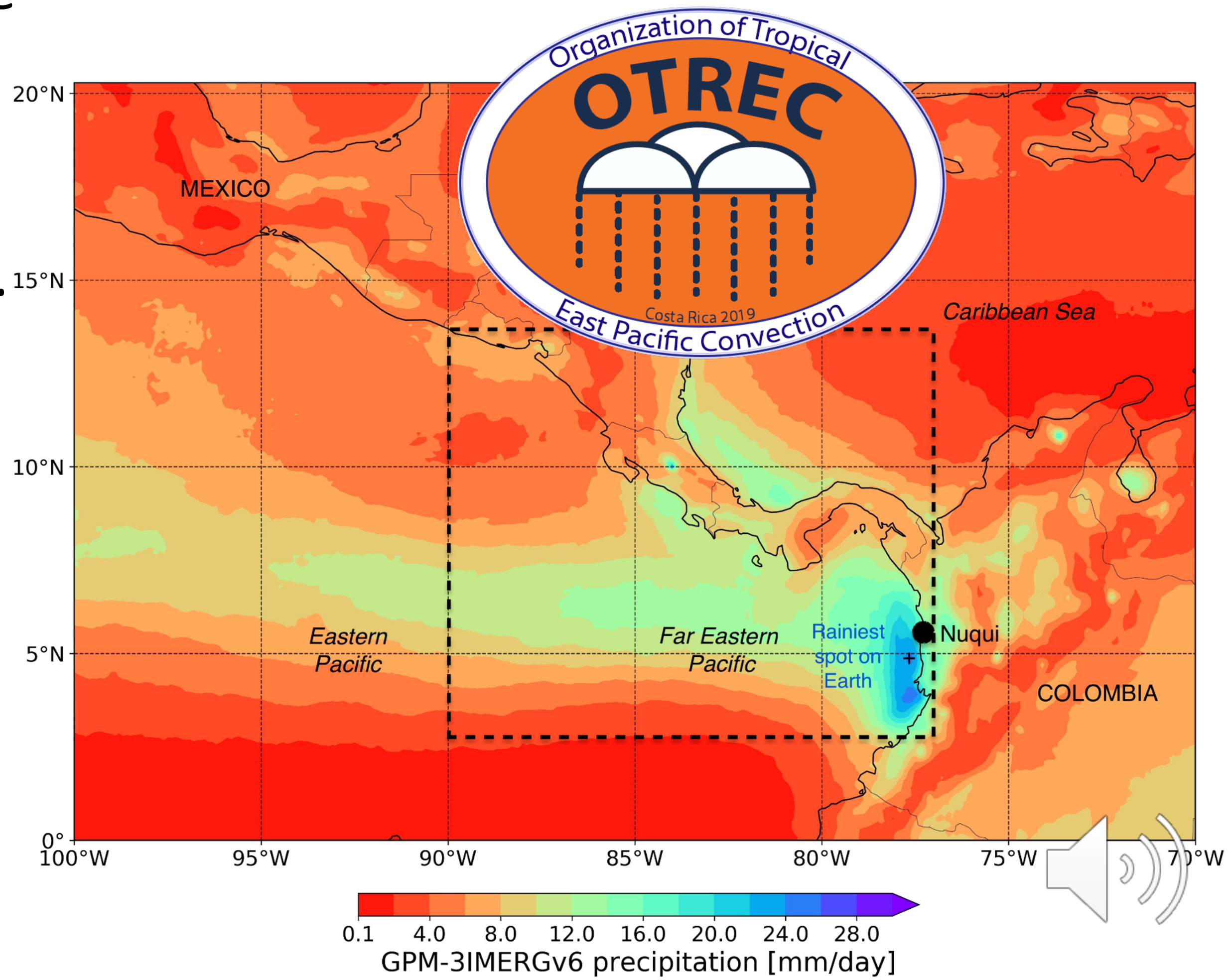
John F. Mejia, *Division of Atmospheric Sciences, Desert Research Institute, Reno, Nevada*

and

Juan J. Henao, GIGA, Escuela Ambiental, *Universidad de Antioquia, Colombia*

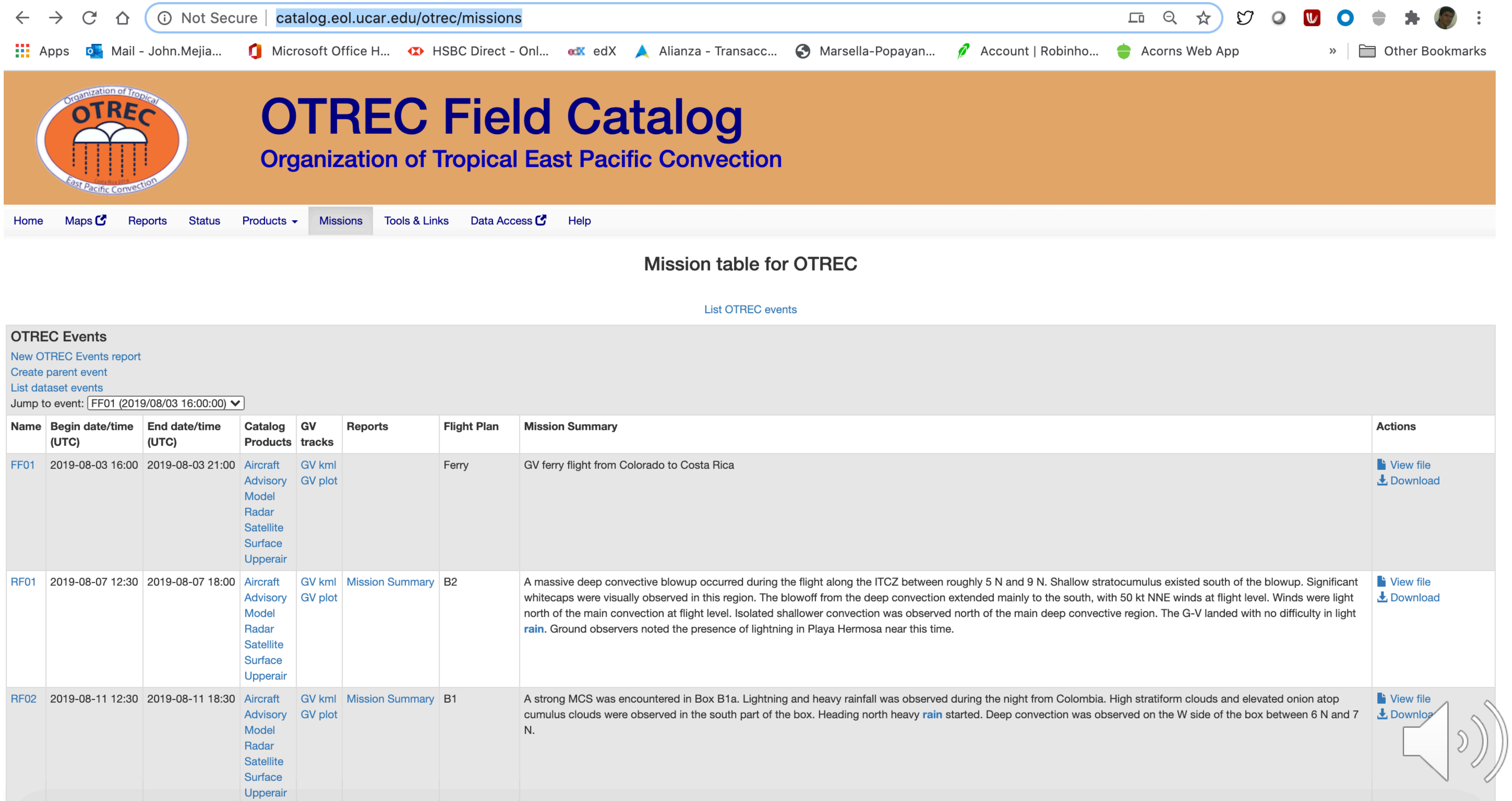
What determines the distribution of deep atmospheric convection over the east Pacific?

- OTREC (Aug-Sept, 2019):
  - Vertical structure of convection; guidance for models and reanalyses.
  - Deep convection with more top-heavy mass flux profiles in stratiform off the Colombia Pacific coast (Fuchs-Stone et al. 2020-GRL).
  - Convection organization is highly related to enhanced southwesterly cross equatorial flow, which interacts with the Andes and coastal Colombian Pacific diurnal oscillation Mejia et al. (2020-JGR-Atm-rev.)

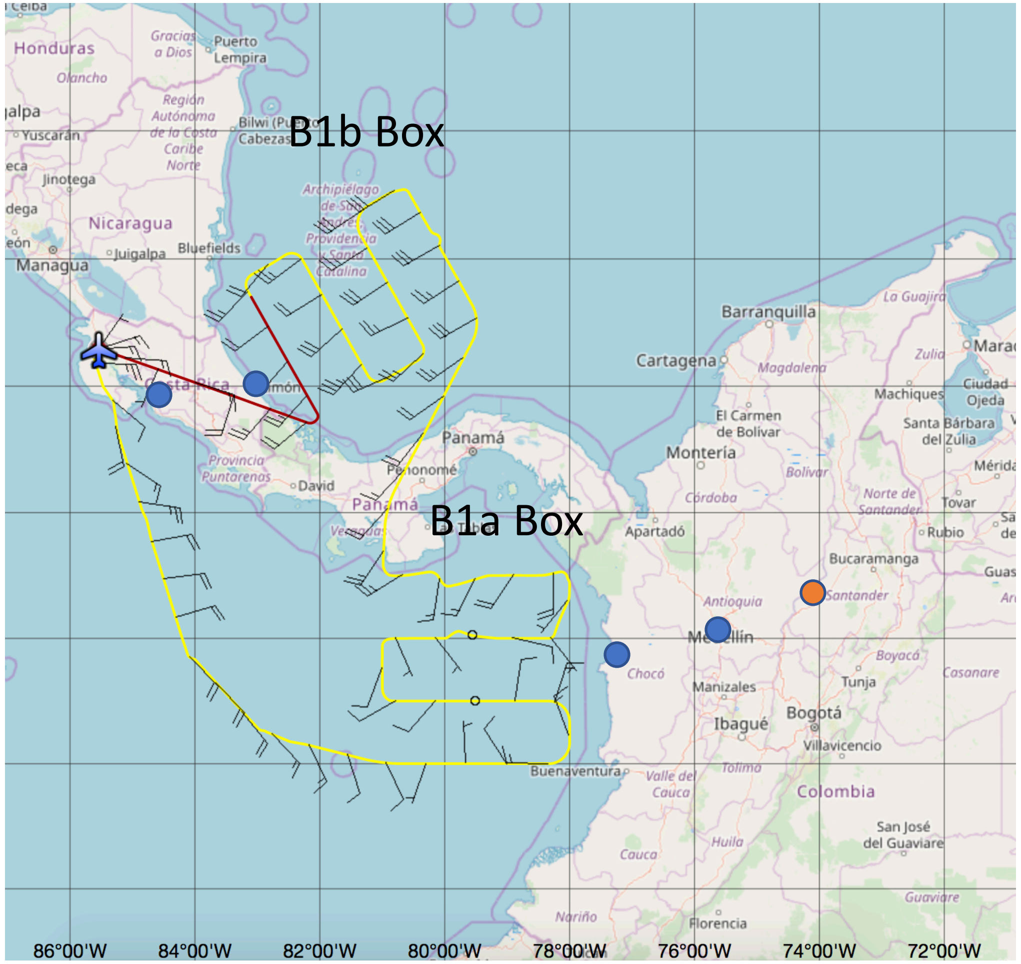


Field Catalog: http://catalog.eol.ucar.edu/otrec/missions

22 Research flights; 9 of which took place off the Colombian Pacific coast.

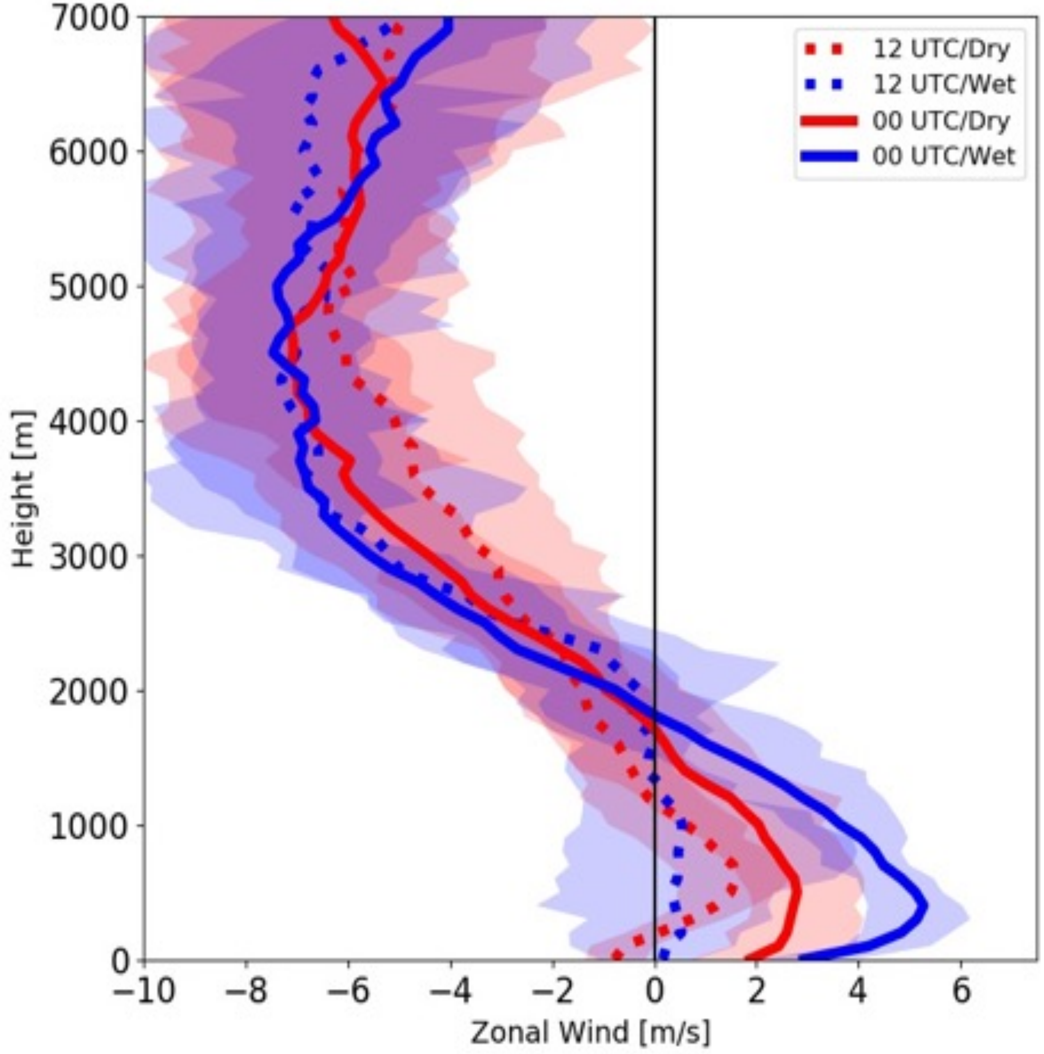


NSF/NCAR Gulfstream-V flight tracks and special radiosondes

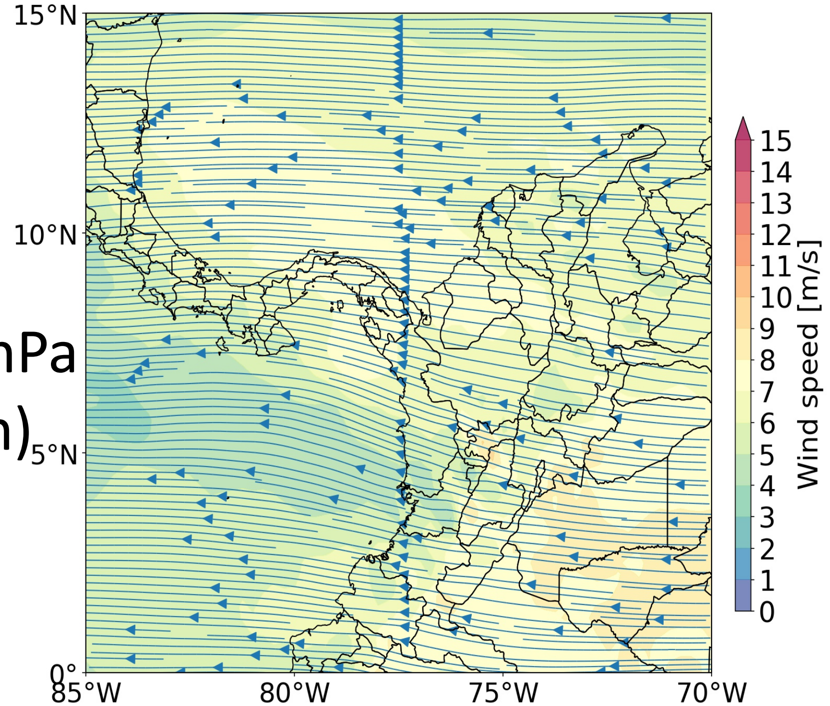


The regional and local circulation

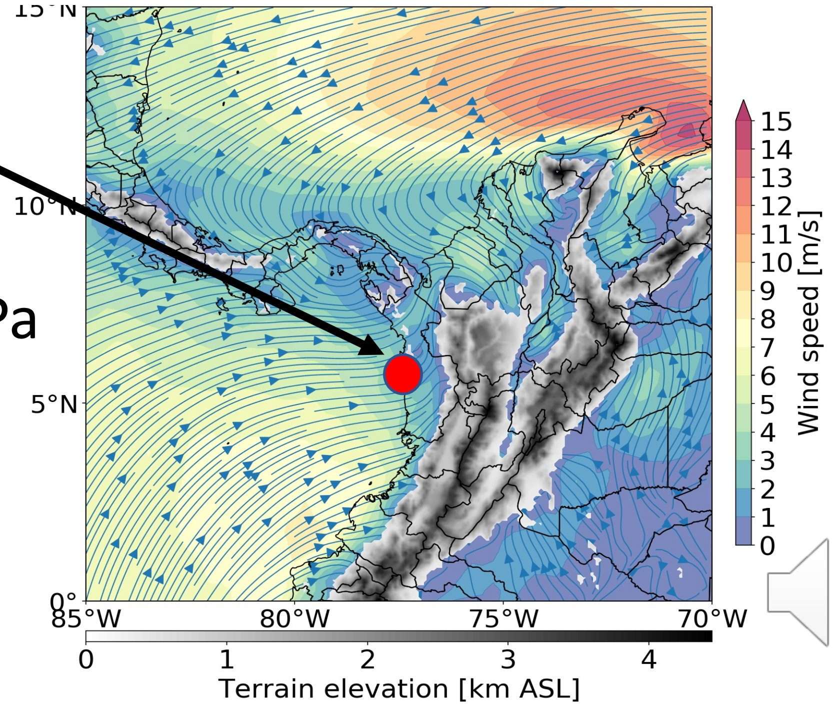
Nuquí



ERA5 500 hPa (~5500 m)

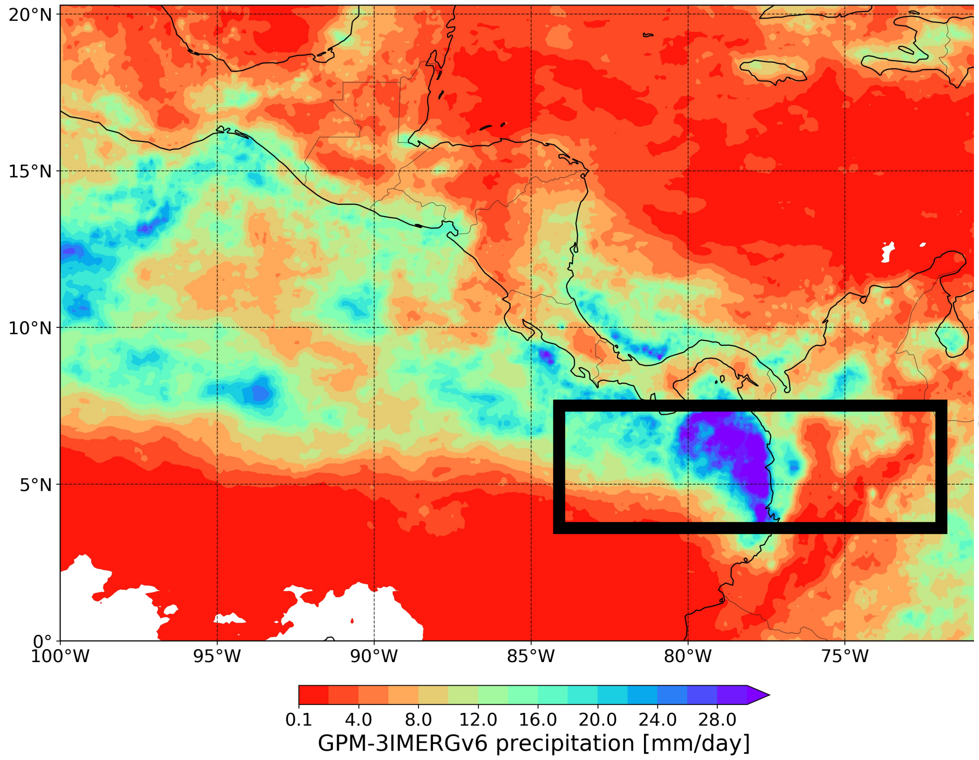


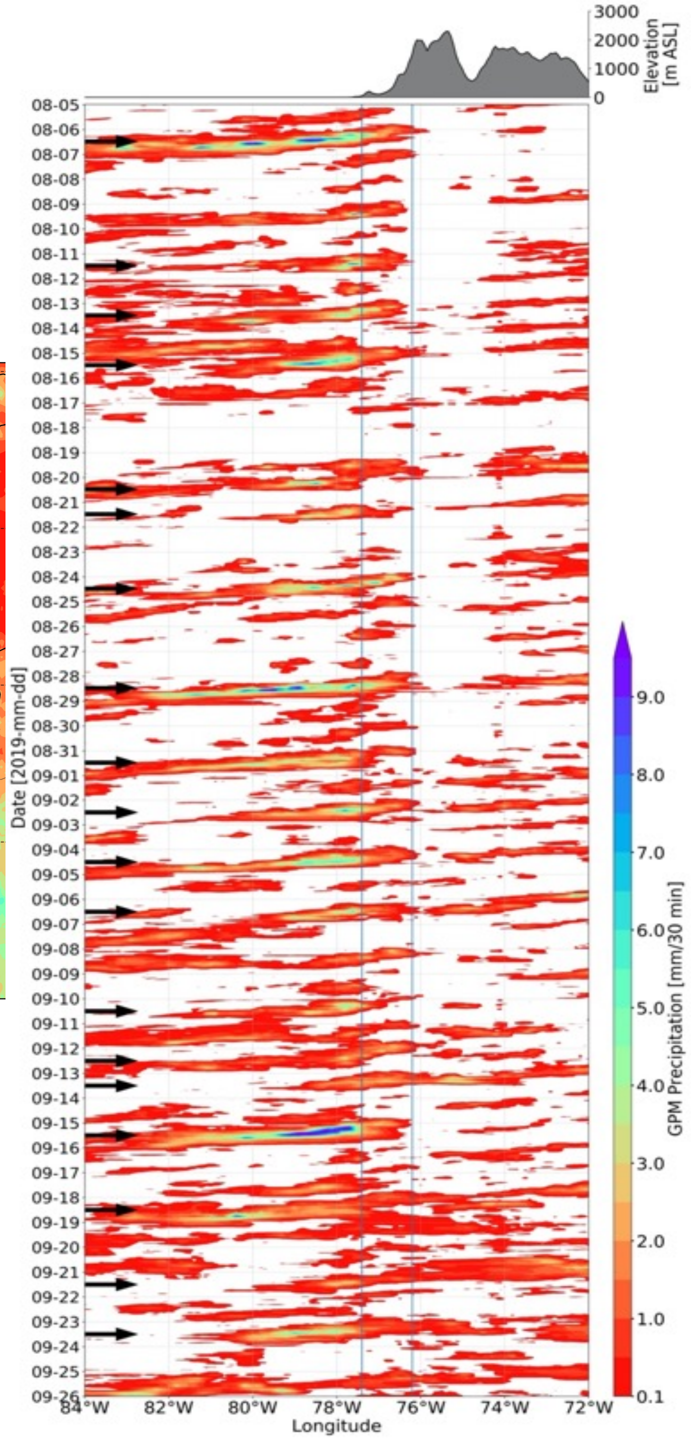
ERA5 950 hPa (~500m)

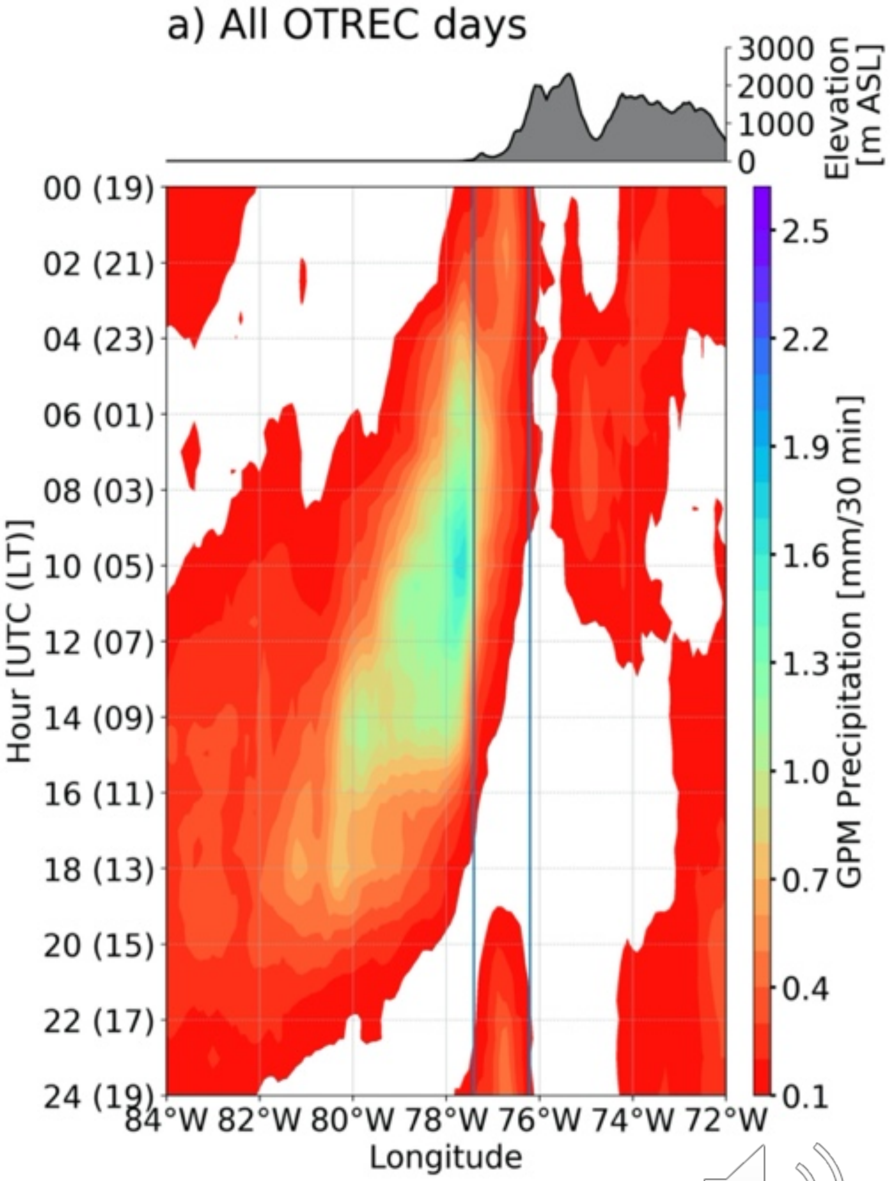


Mejia et al. (2020-JGR-Atm-rev.)

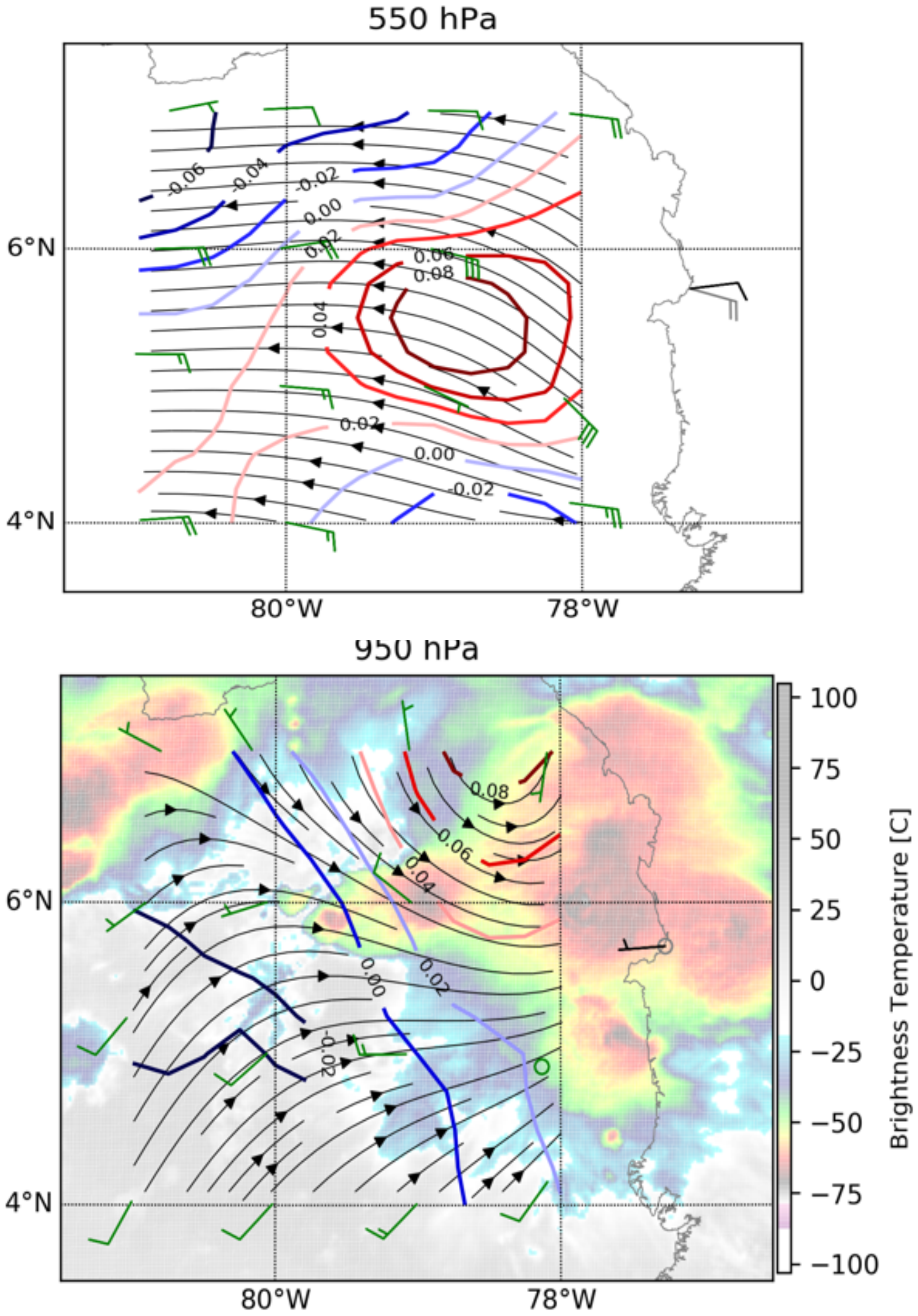
GPM Precipitation patterns during Aug-Sept, 2019

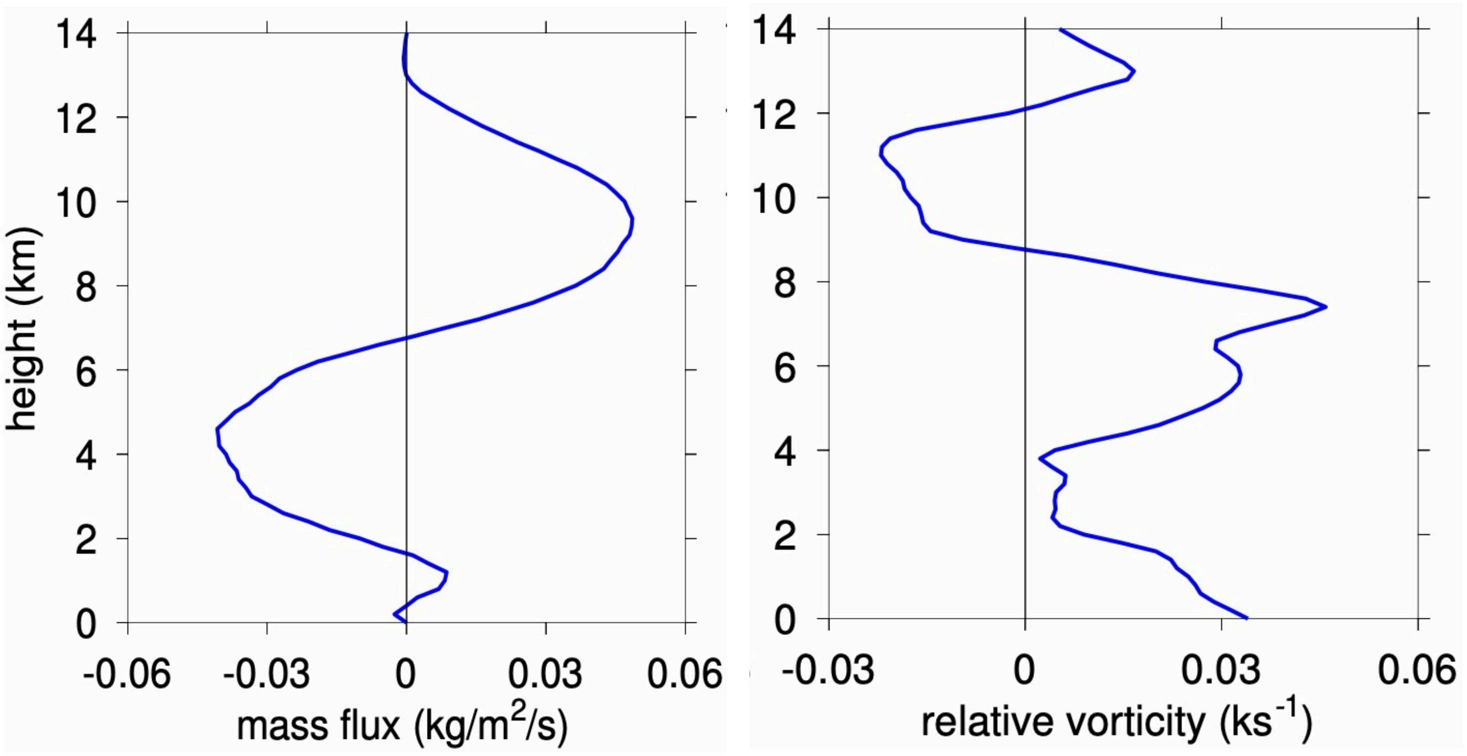






Mejia et al. (2020-JGR-Atm-rev.)





MCSs event during August 11, 2019 (GV-RF02) and 3DVAR analysis

Nuquí soundings at 12 UTC (grey) and 18UTC (black)

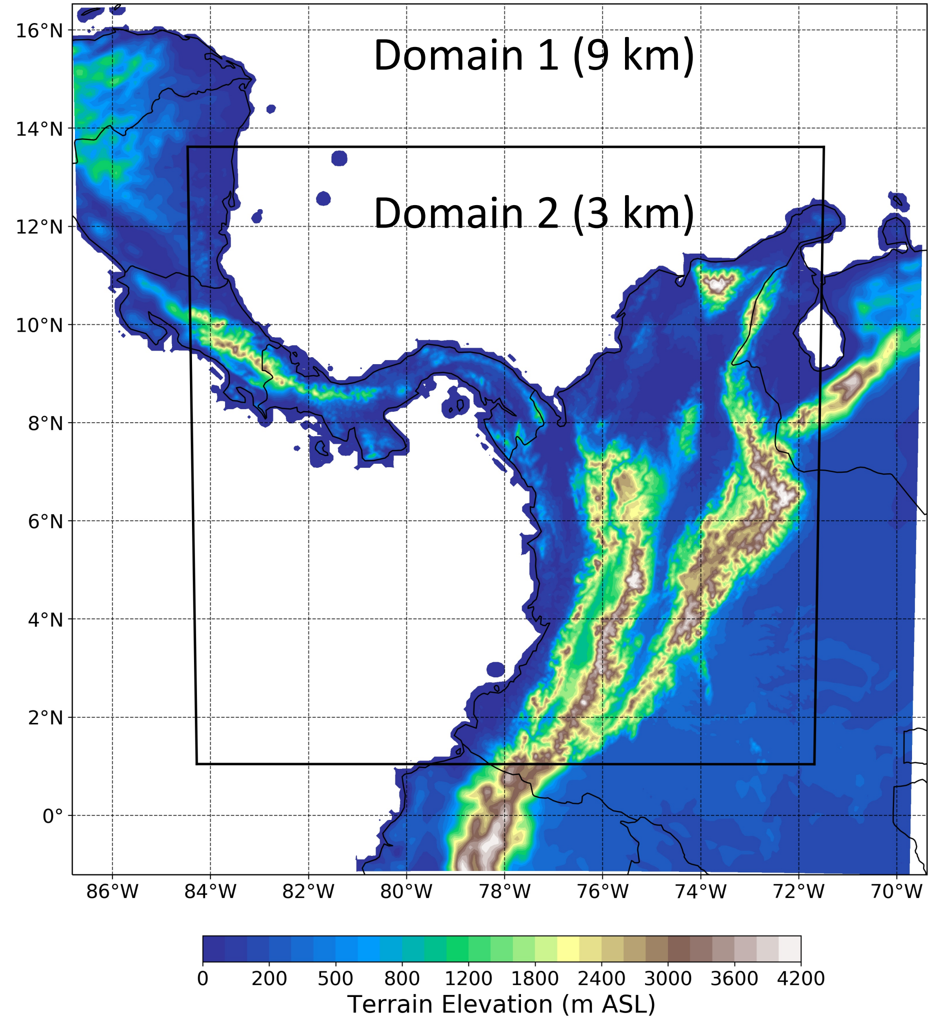
Mejia et al. (2020-JGR-Atm-rev.)

Our modeling research questions are:

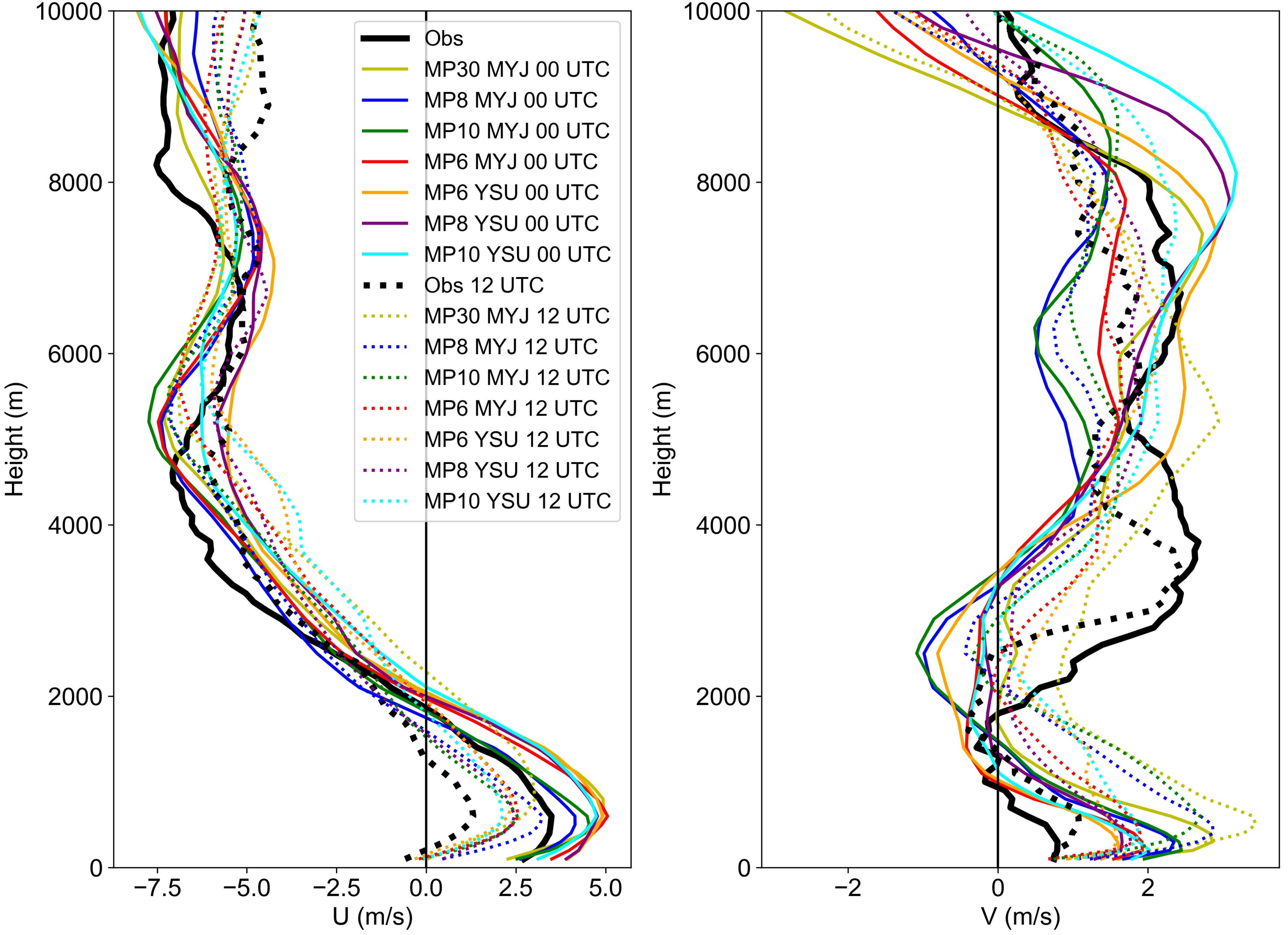
1. Can CRM develop MCSs and related mesoscale circulation and precipitation characteristics off the coast of Colombia and Panama?
2. What are the environmental conditions favoring MCSs development/propagation?
3. Do the MCSs develop for the “right” conditions, i.e., as shown in Mapes et al. (2003-MWR), Yepes et al. (2019-BAMS, 2020-MWR), Mejia et al. (2020-JGR-Atm-rev)?
4. Is the region a source of internal variability {of vortices and energy} capable of modulating EPAC tropical cyclogenesis?

WRF(4.1)-cloud-resolving model mode:

- ERA5 (with assimilation of OTREC data)
- Domain 1: 9 km (211 x 221)
- Domain 2: 3 km (472 x 469)
- 71 vertical layers
- NOAH-MP, CAM
- Domain 1 (Convective parameterization K-F); Domain 2 cloud-resolving



	MP6	MP8	MP10	MP30
Microphysics	WSM-6 (Bulk)	Thompson (Bulk)	Morrison (Bulk)	Spectral Bin-HUJI-fast (Bin)
PBL1, PBL2	MYJ (local) YSU (non-local)	MYJ (local) YSU (non-local)	MYJ (local) YSU (non-local)	MYJ (local)



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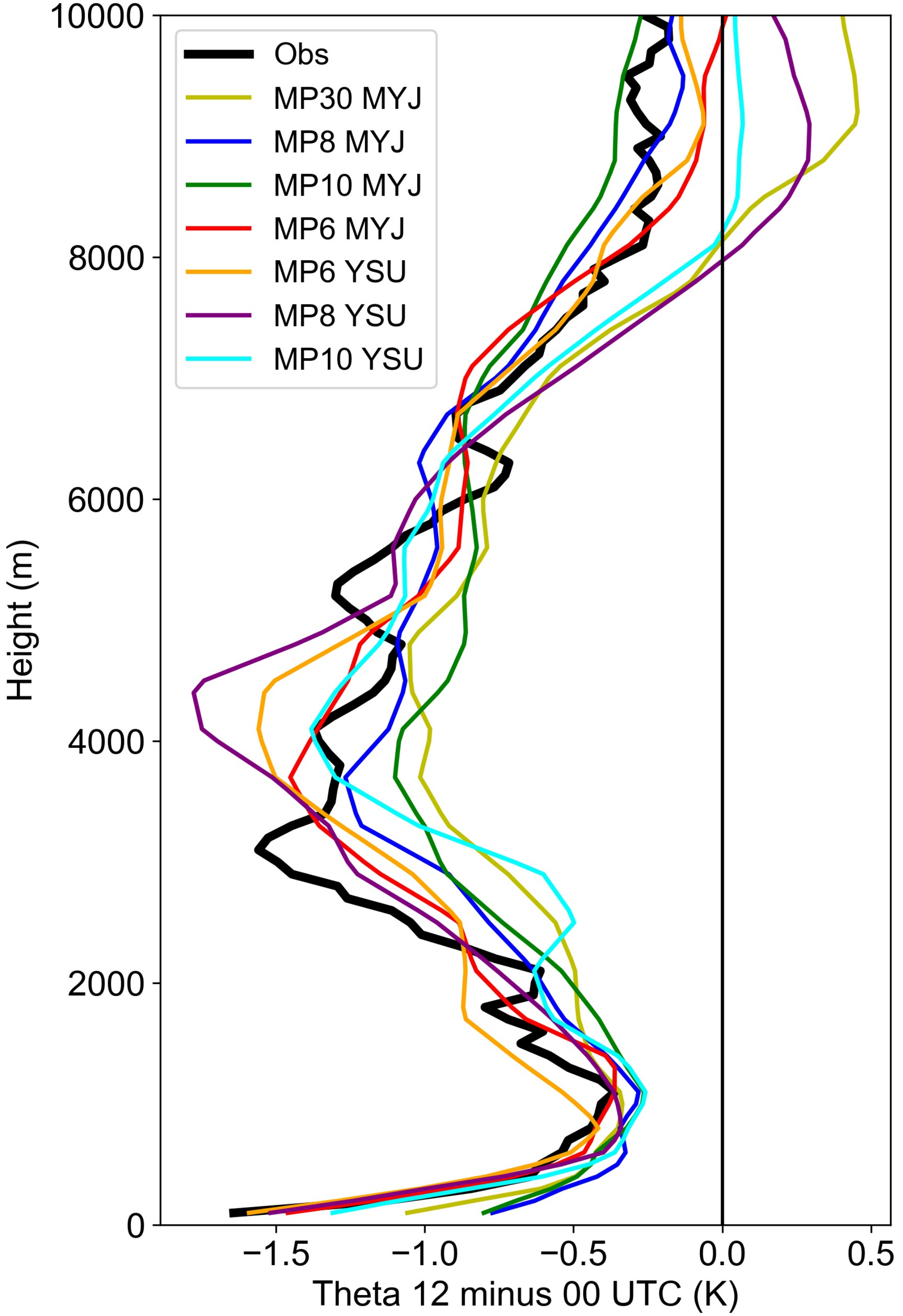
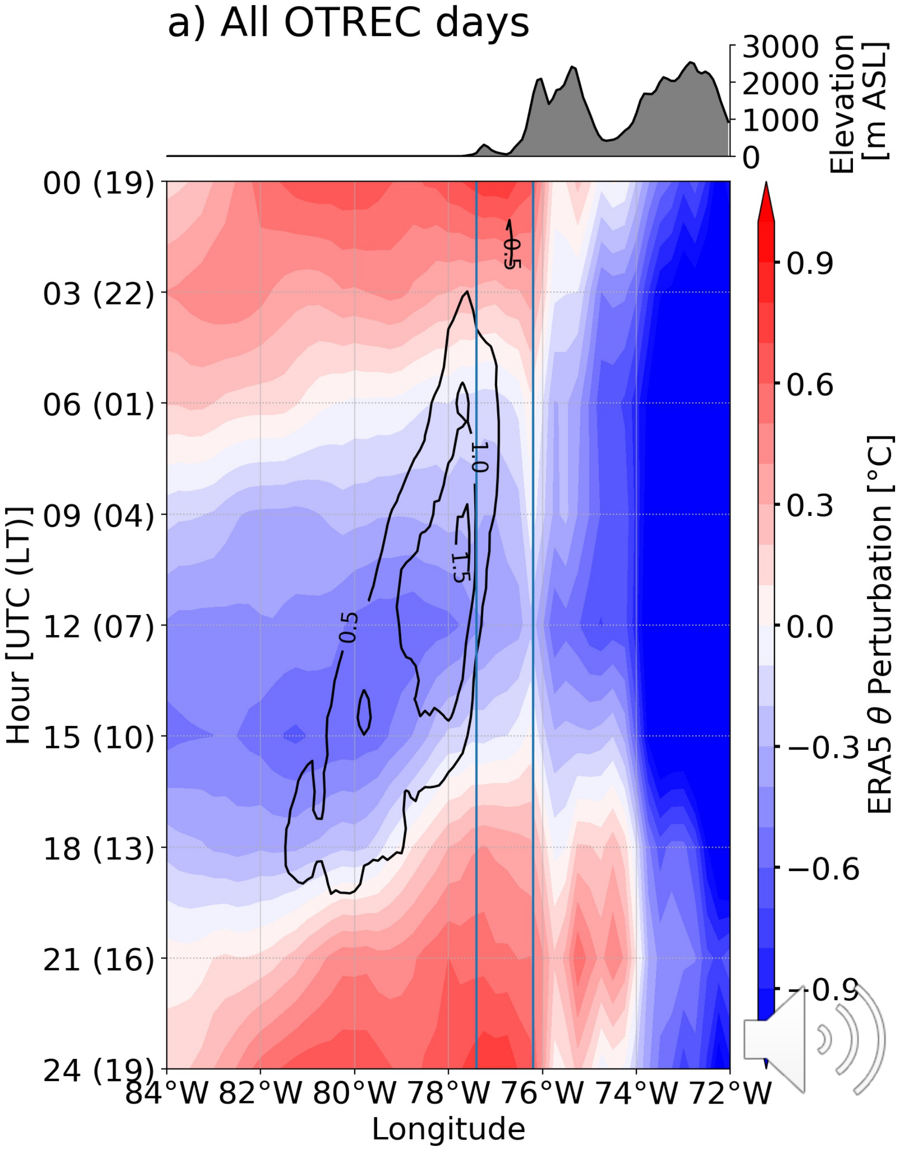
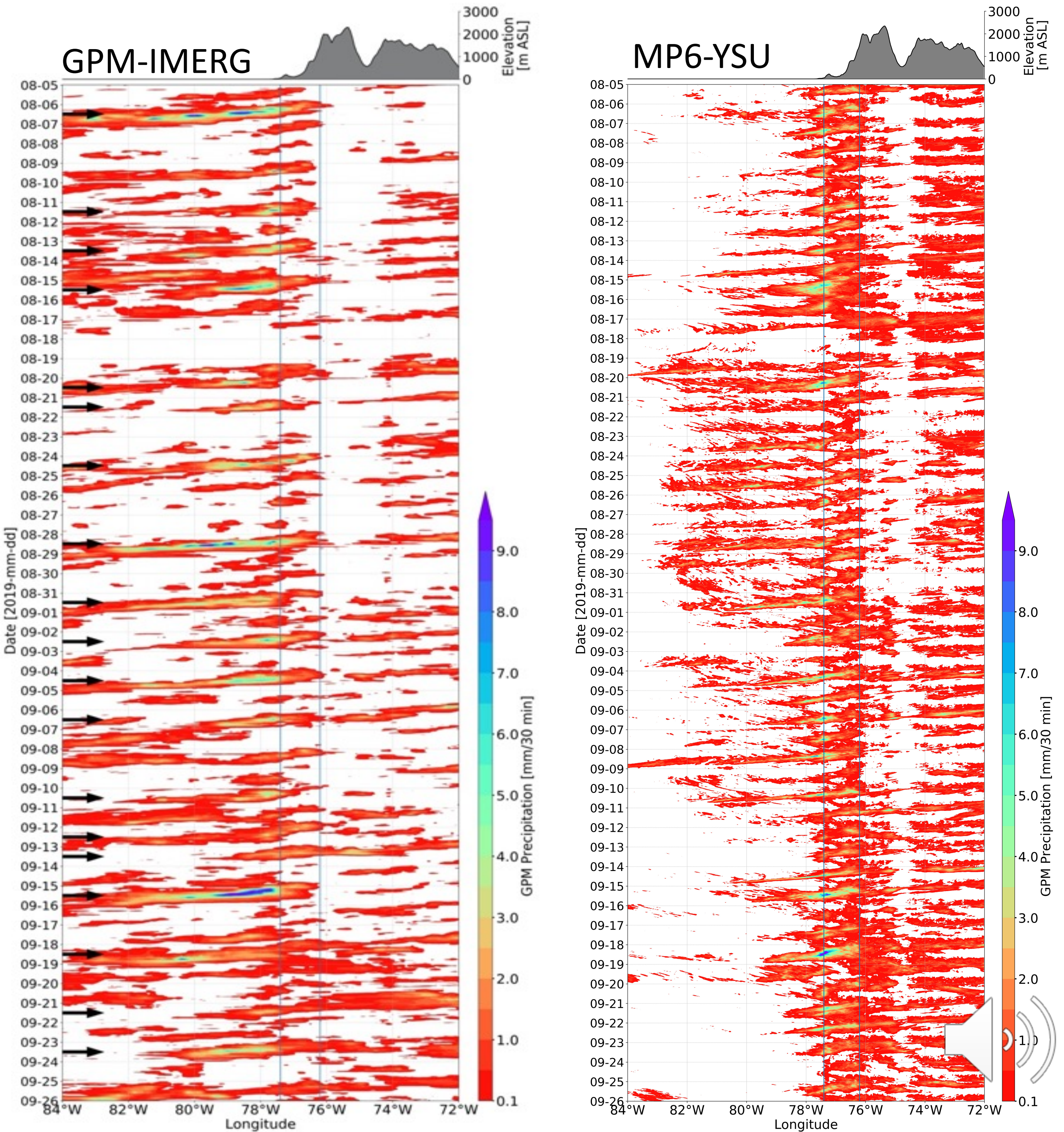


- Diurnal thermal differences are realistic

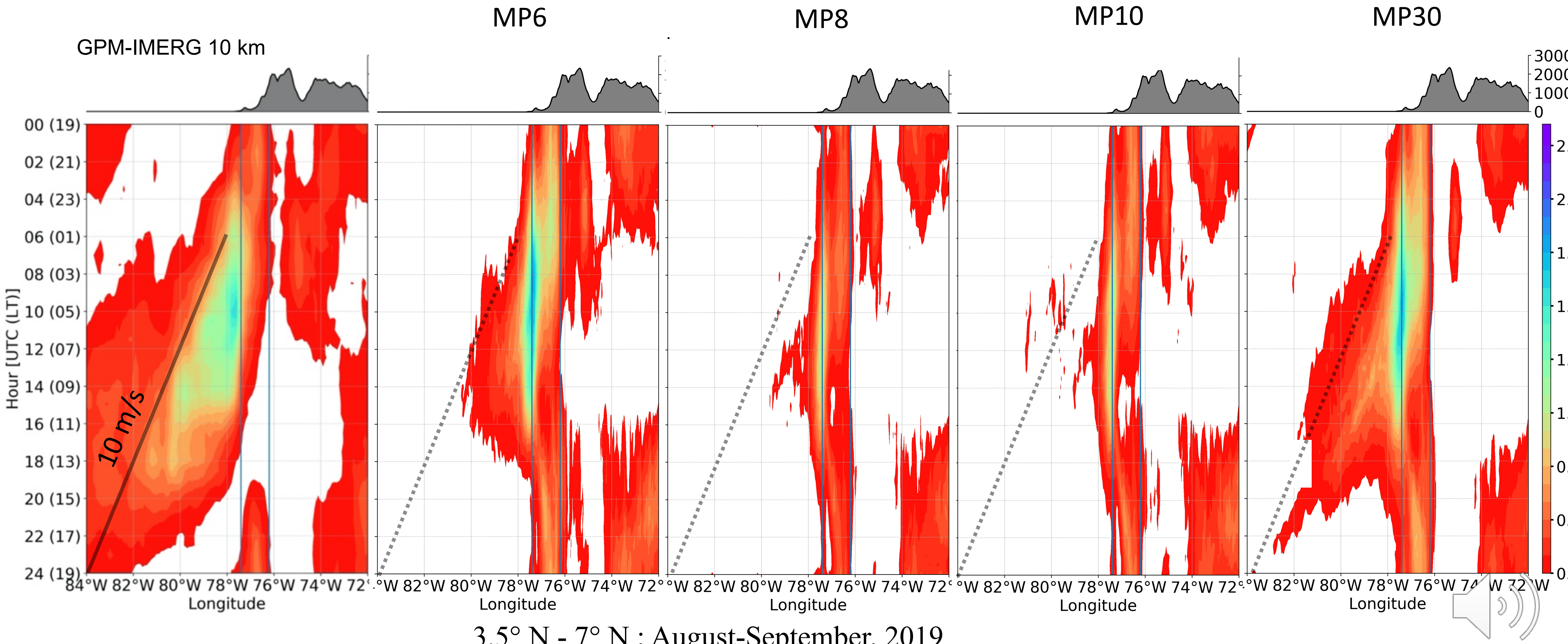
ERA5 650 hPa
(~3500 m)



Model adequately simulates westward moving convective clusters.

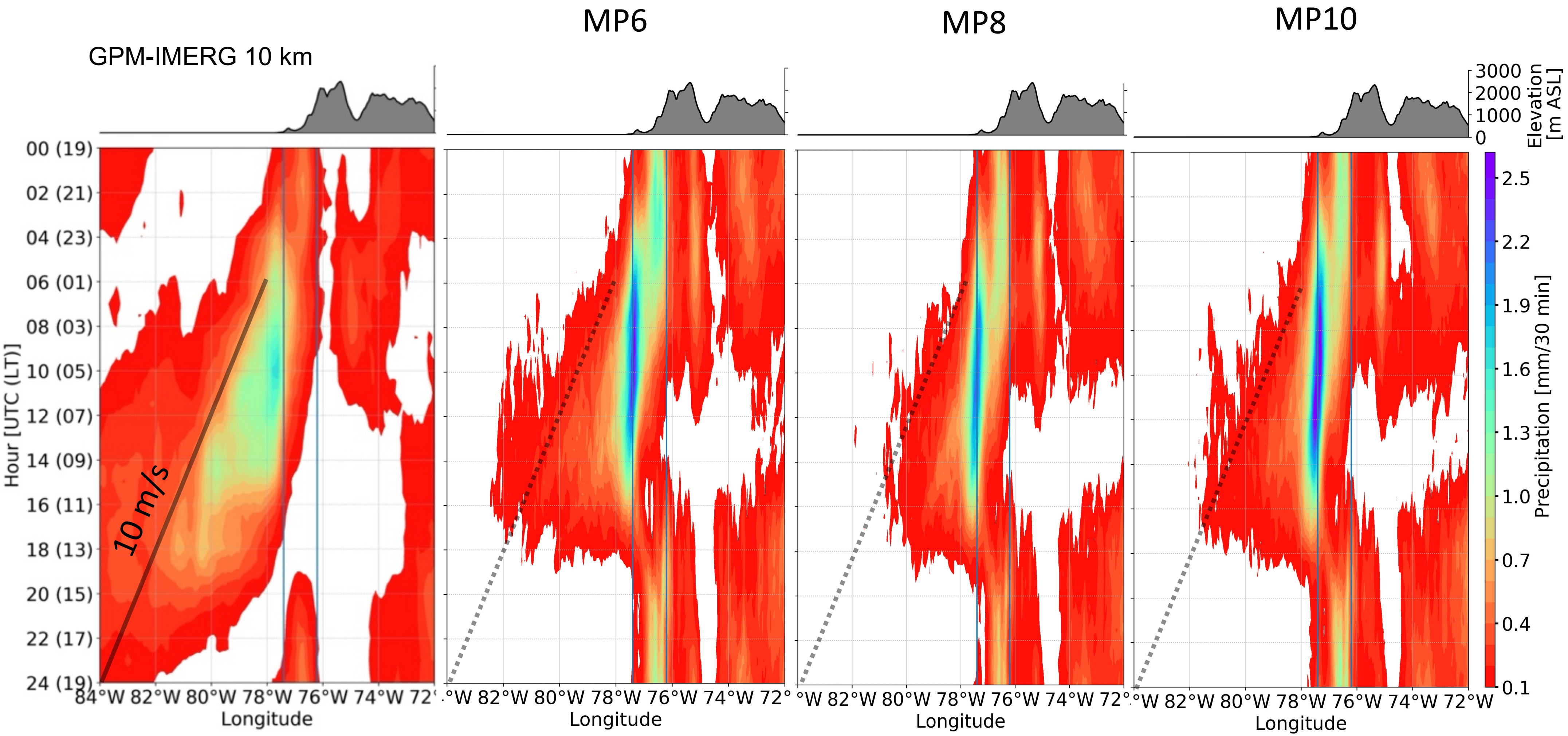


Diurnal Cycle: MP vs PBL (MYJ)



3.5° N - 7° N ; August-September, 2019

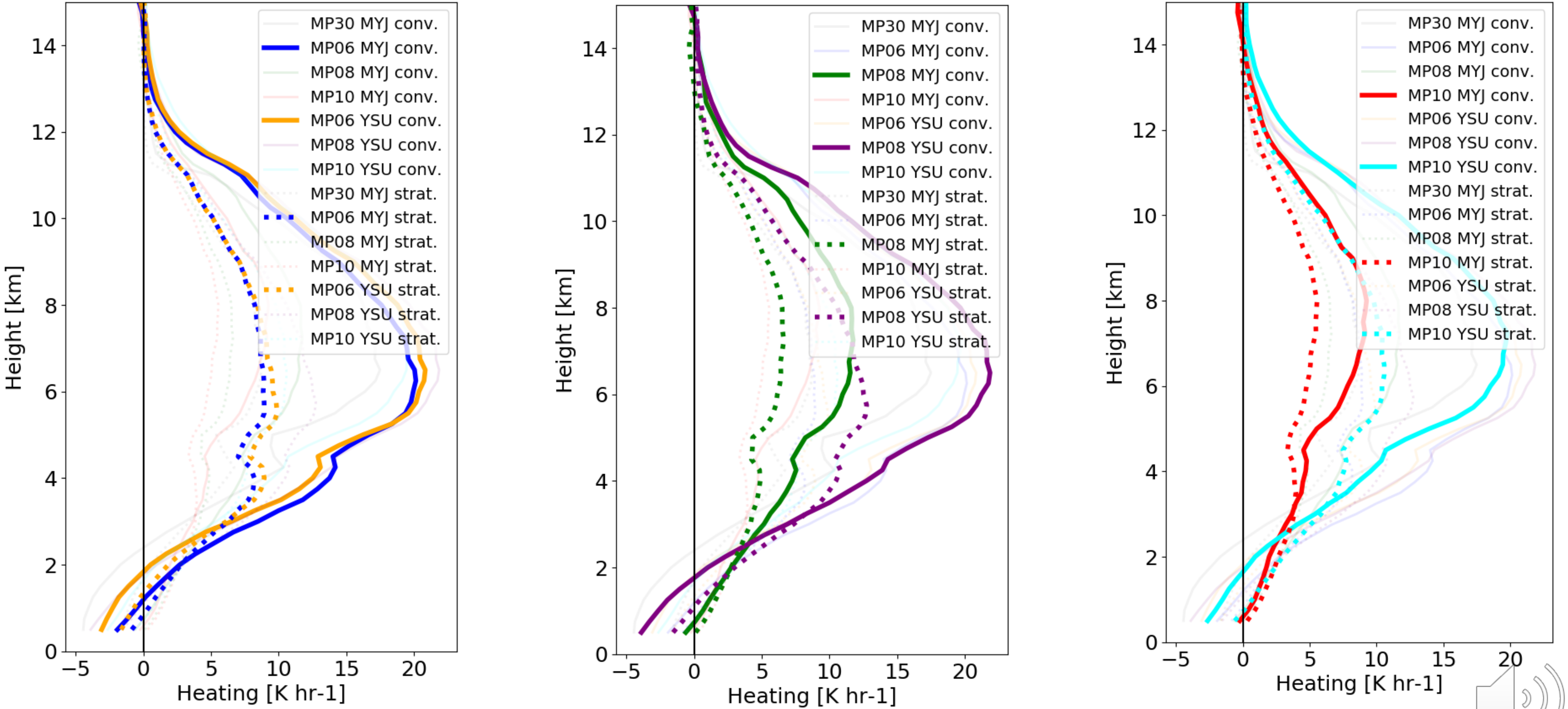
Diurnal Cycle: MP vs PBL (YSU)



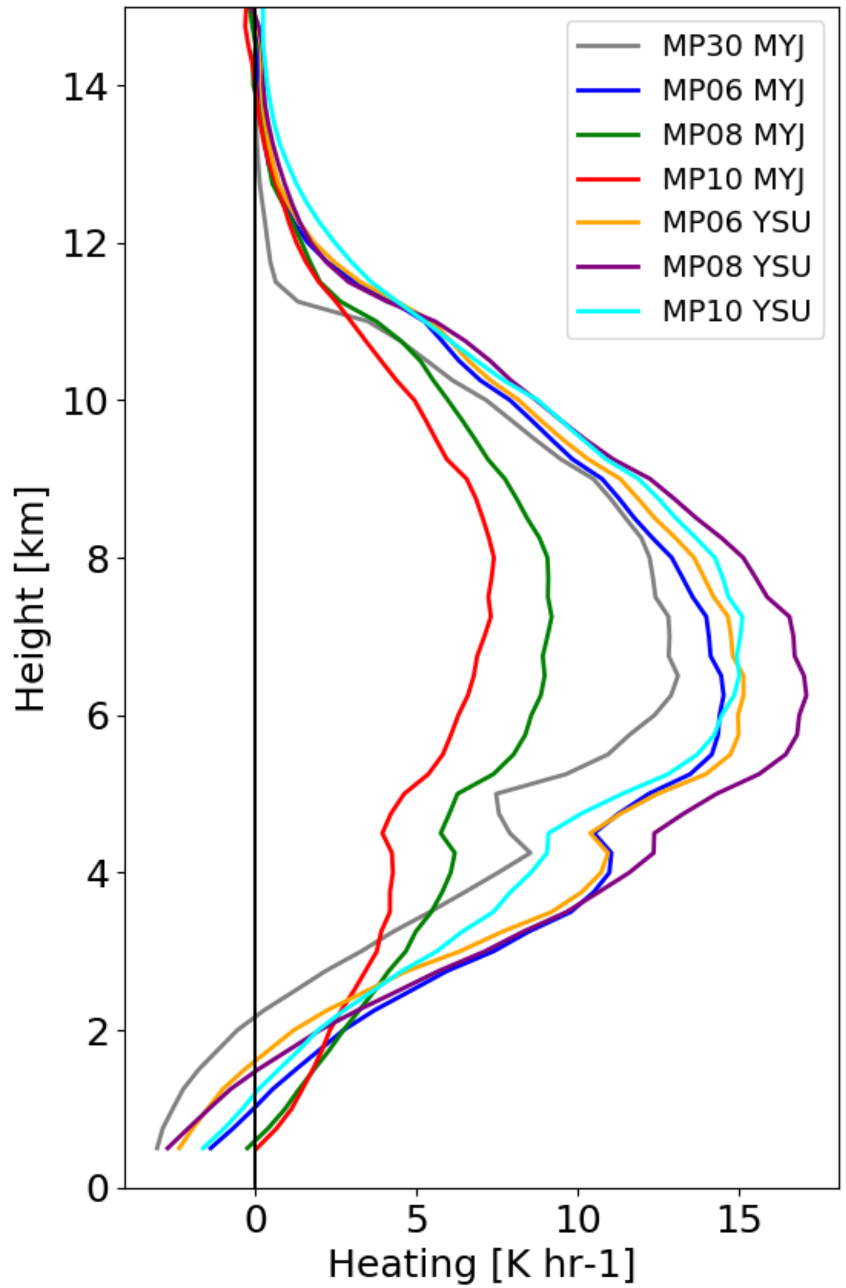
3.5° N - 7° N ; August-September, 2019

Diabatic heating profiles sensitivity to PBL

recall that more westward propagation of precipitation when using YSU



YSU helps develop more top-heavy heating and more low-level cooling



Westward propagating precipitation is very sensitive to microphysics parameterization and PBL

MCSs live longer with MP6 and MP30, but MP8 and MP10 are more favorable to westward moving MCSs when PBL is switched from MYJ to YSU.

Summary and Conclusions

- From observations and modeling results: We hypothesize that a robust stratiform region tends to enhance the top-heavy (mass-flux) heating profiles and favor longer-lived MCSs propagating westward off the Colombian Pacific coast.
- The role of convective outflows in such propagation is intriguing. More analysis is needed to assess how the outflows interact with the ChocoJet and the environmental vertical shear.
- Spectral bin (MP30) and WSM-6 (MP6), both on opposite ends in the hierarchy and complexity of the microphysics schemes, revealed similar propagating characteristics.
- Thomson (MP8) and Morrison (MP10) microphysics parameterizations were more sensitive to PBL schemes ; when switching from MYJ to YSU, longer-lived westward moving MCSs were favored.

Acknowledgements

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- *We also thank NASA for providing the GPM dataset.*