Assessing the vertical structure of the east Pacific ITCZ using the Cloudsat CPR and TRMM PR

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Introduction

The Intertropical Convergence Zone (ITCZ) is a zonal band of low-level wind convergence, cloudiness, and rainfall that acts as an important part of the ascending branch of the Hadley Circulation (Fig. 1). There is debate on the vertical structure of the ITCZ in the east Pacific, particularly whether the profiles of latent heating and vertical velocity are top- or bottom-heavy (Fig. 2).

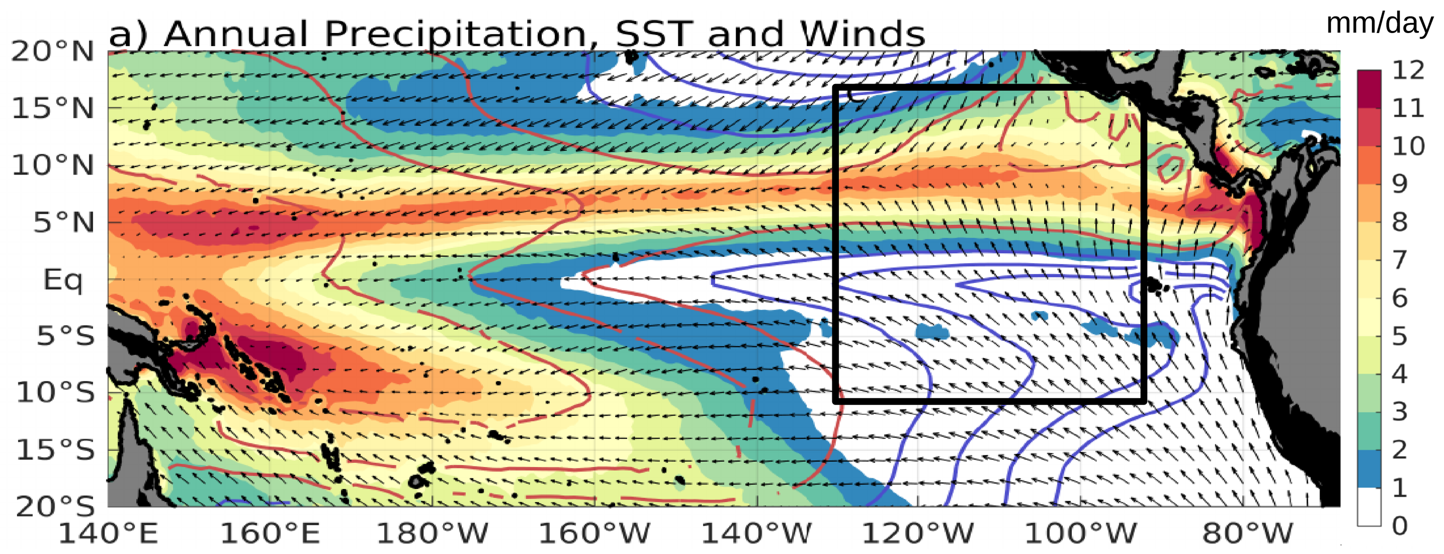

Figure 1: Mean 1998-2015 precipitation from TRMM 3B43 (shading), sea surface temperature from the TRMM TMI (contours) and surface wind from CCMP (vectors).

Atmospheric reanalysis data for the eastern Pacfic ITCZ indicate a bottom-heavy structure, with shallow maximum ascent driven by the meridional SST gradients (Back and Bretherton 2006), while most methods for estimating the vertical structure of the rate of latent heating, which rely on profiles from field campaign observations in other regions combined with convective/stratiform fractions from the Tropical Rainfall Meassure Mission (TRMM) satellite (e.g., Schumacher et al. 2004), suggest a top-heavy structure.

Recent studies based on in-situ data show a double meridional circulation during the fall and spring suggesting a double omega peak (Huaman and Takahashi 2016).

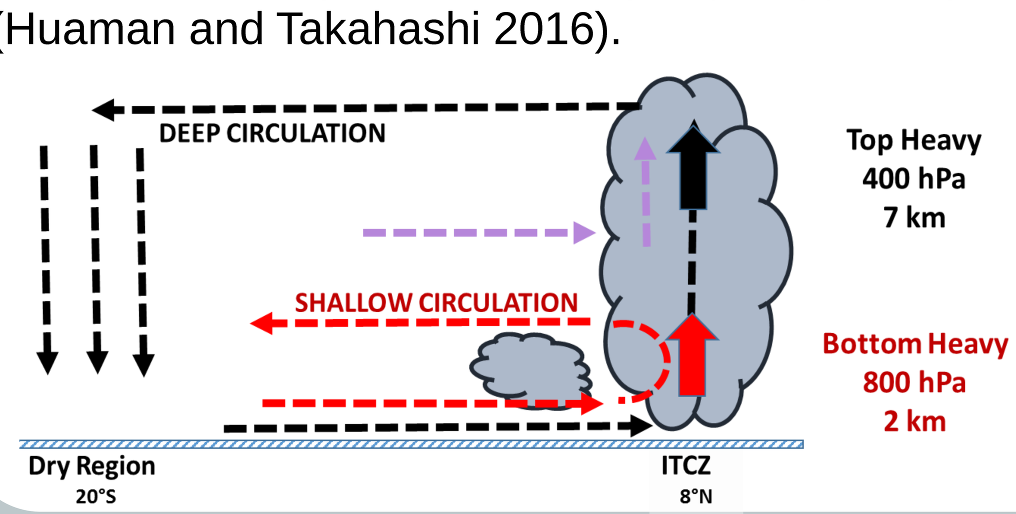

Figure 2: Schematic meridional–vertical diagram. "Bottom heavy" (red), "top heavy" (black), mid-level inflow from simulations (Nolan et al. 2010; purple)

Data and Methodology

We use surface precipitation from the TRMM PR (2A25 product) and CloudSat CPR (2C-PRECIP-COLUMN) for 1998-2015 to assess the vertical latent heating structure in the east Pacific ITCZ (130°W-90°W).

Stratiform, deep convective and congestus rain are taken from the TRMM PR and shallow rain from the CloudSat CPR since the CPR has a higher sensitivity to light rain. Our latent heating profile look-up table is inspired by Schumacher et al. (2004); however, some modifications based on recent studies were implemented (Fig. 3).

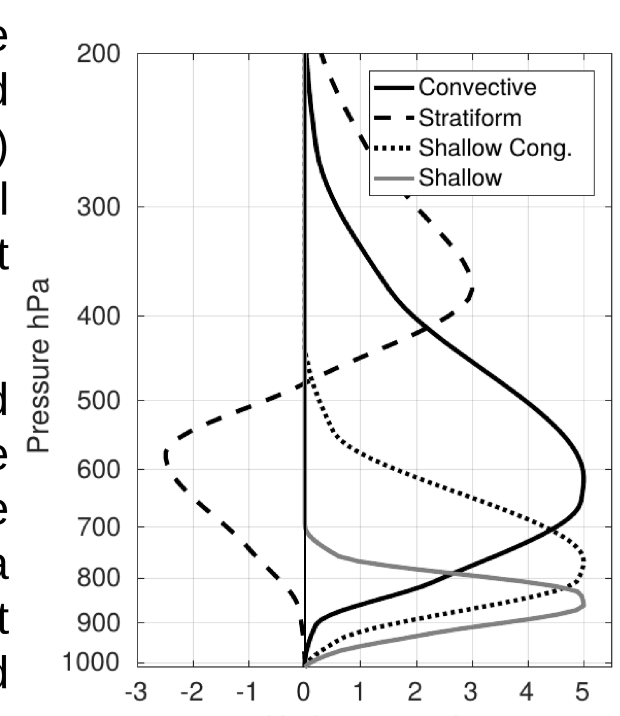

Figure 3: Nodimensional LH profiles for stratiform, deep convective, congestus and shallow rainfall

Additionally, we compare our latent heating results with algorithms that are TRMM-based [Convective Stratiform Heating (CSH), Spectral Latent Heating (SLH, and PR Heating (PRH)] and reanalysis-based (total diabatic heating from MERRA2, ERA-Interim and NCEP-NCAR).

Main References

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- Huaman, L., & Takahashi, K. (2016). The vertical structure of the eastern Pacific ITCZs and associated circulation using the TRMM Precipitation Radar and in situ data. Geophysical Research Letters, 43(15), 8230-8239.
- Nolan, D. S., Zhang, C., & Chen, S. H. (2007). Dynamics of the shallow meridional circulation around intertropical convergence zones. Journal of the atmospheric sciences, 64(7), 2262-2285.
- Schumacher C., R. A. Houze Jr., and I. Kraucunas (2004) The Tropical Dynamical Rensponse to Latent Heating Estimates Derived from the TRMM Precipitation Radar. *J. Atmos. Sci.,* 61, 1341-1358.

Cloudsat CPR and TRMM PR

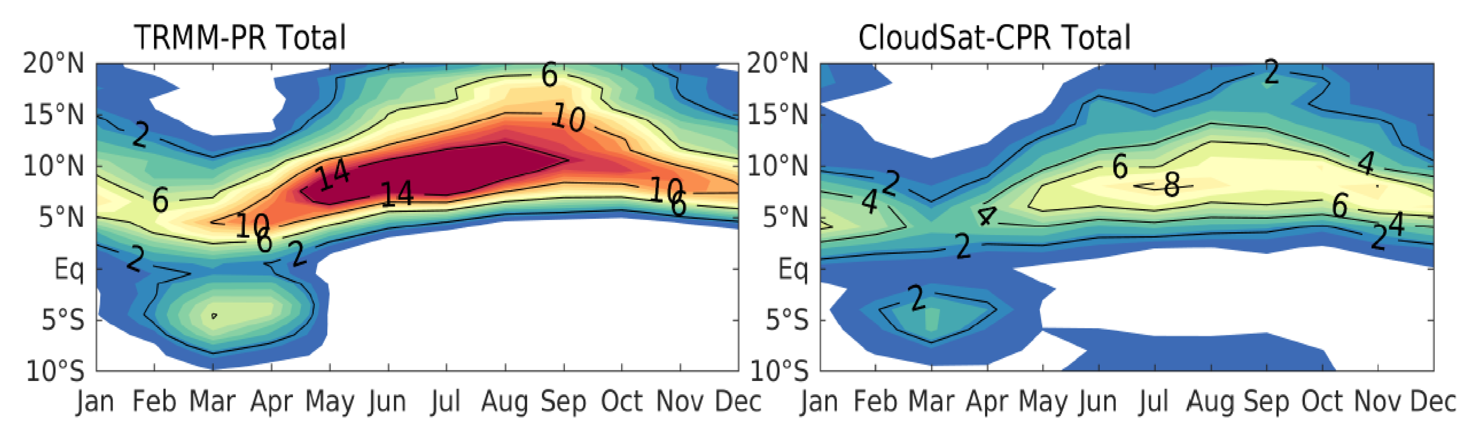

Figure 4: Total surface precipitation from the TRMM PR and CloudSat CPR in the east Pacific ITCZ (130W-90W) in mm/day.

The total precipitation from the CPR is weaker than the PR (Fig. 4) because of the CPR's attenuation; however, both satellite radars agree on the seasonal variability and latitudinal structure of the east Pacific ITCZ. During boreal spring, a double ITCZ symmetric to the equator is observed; during summer and fall, the ITCZ is intense and further north.

The CPR (W-band) has a high sensitivity to shallow precipitation (Fig. 5a); however, it suffers strong attenuation in deep convection (Fig. 5c). The PR (K_u-band) allows good observations of stratiform and deep convective rain (Figs. 5b and c), but underestimates shallow precipitation. We combine observations from both radars to overcome their independent disadvantages. Our total precipitation corresponds to the sum of the deep convective and stratiform rain from the PR and the shallow rain from the CPR. The latent heating profiles were estimated from this new total precipitation and the look-up table in Fig. 3.

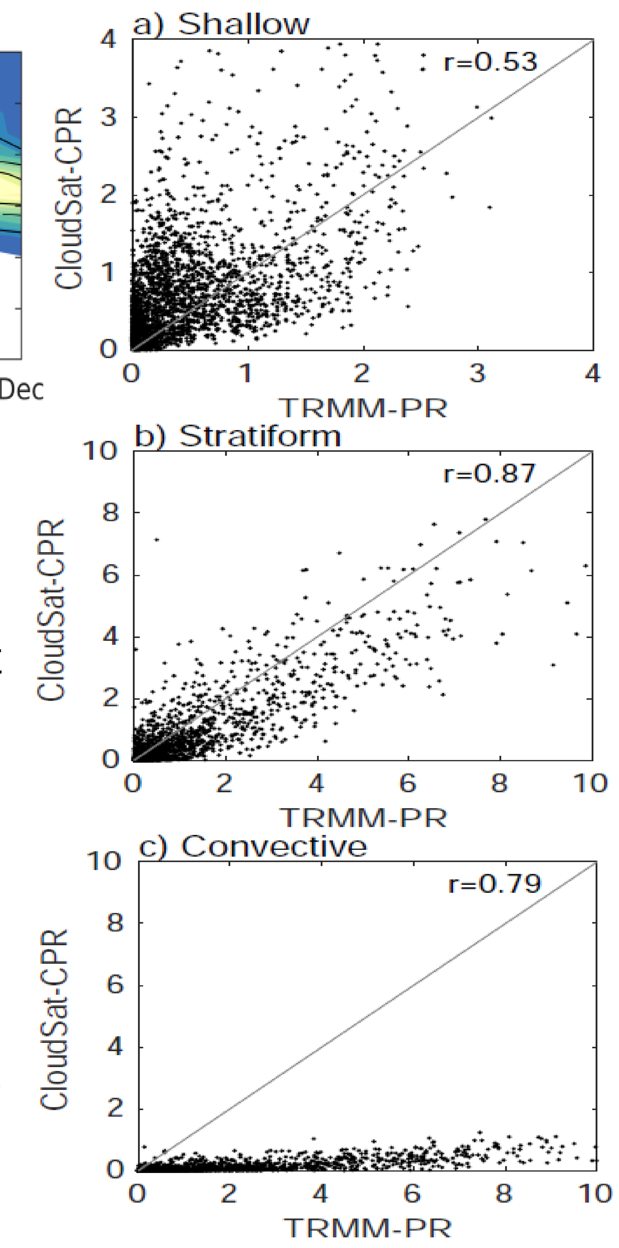

Figure 5: Scatterplot of shallow (a), stratiform (b), and deep convective (c) precipitation from the CPR and PR in mm/day

Latent Heating in the east Pacific ITCZ

The mean 1998-2015 latitude-pressure cross-sections of the PR-CPR latent heating (Figs. 6a-d) suggest a bottom-heavy structure during boreal winter and spring with a peak around 800 hPa. Otherwise, a double peak is observed during summer and fall around 850 hPa and 400 hPa. Our latent heating profiles agree to varying degrees with other PR-based algorithms (Figs. 6 e-h), although our vertical latent heating integrals (equivalent to the surface precipitation) match most closely with the CSH V7 (green).

The total diabatic heating (Q_1) from reanalyses (Figs. 6i-l) have similar strongly bottom-heavy structures and magnitudes during winter, spring and fall. However, during summer, Q_1 is distributed throughout the troposphere according NCEP/NCAR and ERA-Interim, while MERRA2 shows maximum Q_1 around 400-600 hPa suggesting a top-heavy structure.

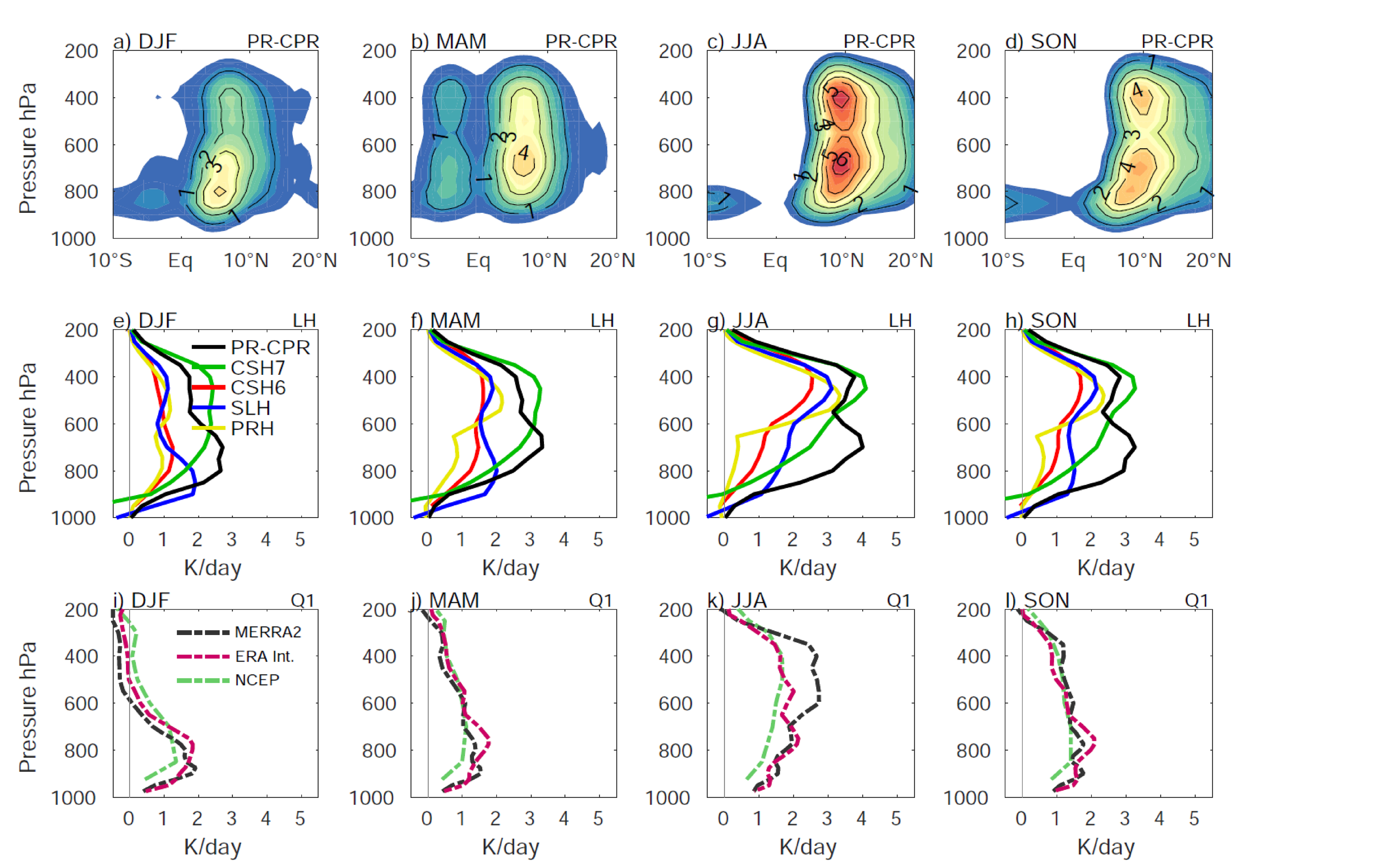

Figure 6: Seasonal pressure-latitude structure of latent heating using CloudSat and TRMM (a-d). Vertical profiles of latent heating in the ITCZ region from TRMM-based algorithms (e-h). Q_1 profiles in the ITCZ regions from reanalyses (j-l).

Conclusions

- We successfully combined observations from the CloudSat CPR (which attenuates in deep convection) and TRMM PR (which underestimates light rain) to determine monthly profiles of latent heating in the east Pacific ITCZ.
- NCEP/NCAR, ERA-Interim and MERRA2 reanalysis products suggest a strong bottom-heavy structure throughout the year, except for MERRA2 during summer. This bottom heaviness is not consistent with our results, which show significant latent heating at upper levels associated with radar-observed stratiform and deep convective precipitation, esp. during boreal summer and fall.