Linking Isotopic Depletion of Precipitation to Vertical Profiles of Convective Heating in the East Pacific using Station Observations and Convective-Permitting Simulations

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Introduction

The spatial variability of tropical convective heating in the tropics is a topic of interest. Convection in the west Pacific is generally held to have a top-heavy heating profile, but its vertical structure in the East Pacific is still **ambiguous** in nature:

- TRMM-based observations indicate that deep convection with top-heavy structures dominates across the Pacific (Schumacher & Kraucunas, 2004)
- Reanalysis modelling indicates that east Pacific convection is shallow (i.e., bottom-heavy) in nature (Fig. 1; Back & Bretherton, 2006)

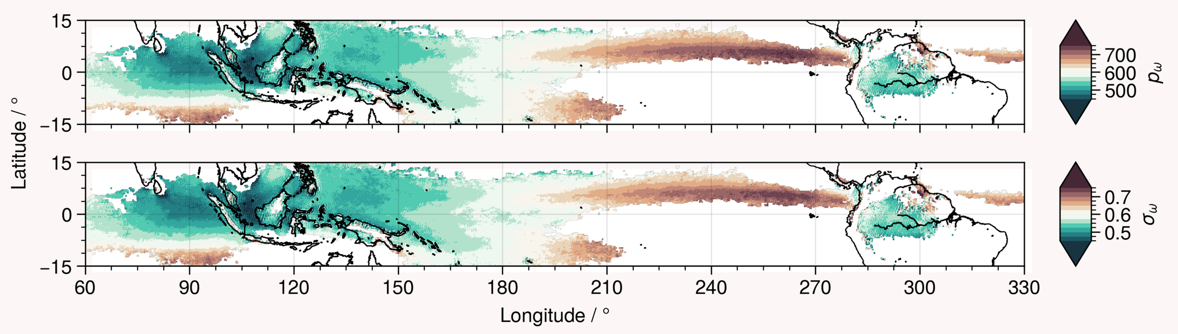


Figure 1: Degree of top- or bottom-heaviness of the convective heating profile over the Pacific basin based on ERA5 Reanalysis datasets.

Depletion of the heavier isotopologues of HDO and $H_2^{18}O$ within rainfall could be used as a proxy for the structure of convective heating:

- Isotopic fractionation within the atmospheric column implies that ***deep convection could result in more depleted rainfall***

- Torri et al. (2017) recently demonstrated proof-of-concept:
  - GNIP rainfall station data w/ isotopic depletion
  - ERA-40 reanalysis-derived monthly vertical profiles
  - Idealized isotope-enabled model simulations in SAM (isoSAM)
  - Realistic isotope-enabled model simulations in CAM (iCAM)

- Our study acts a complement to Torri et al. (2017) with:
  - Station rainfall data from OTREC2019 field campaign (Fuchs-Stone et al., 2020)
  - ERA5 reanalysis-derived 7-day and 30-day averaged vertical profiles
  - Regional ***convection-permitting*** isotope-enabled WRF simulations for OTREC2019

Linking p_ω to Isotopic Depletion

p_ω, or the pressure-velocity-weighted column-mean pressure, is a measure of the top-heaviness of convection:

$$p_\omega = \frac{\langle \omega p \rangle}{\langle \omega \rangle}, \qquad \sigma_\omega = \frac{p_\omega}{p_s}$$

The moisture budget is given by

$$\begin{aligned} \langle \partial_t q \rangle &= -\langle \nabla \cdot (q\boldsymbol{u}) \rangle + E - P \\ &= \langle q \partial_p \omega \rangle - \langle \boldsymbol{u} \cdot \nabla q \rangle + E - P \end{aligned}$$

Over a multi-day moving average of at least 7 days or longer, we can assume that both $\langle \partial_t q \rangle$ and E are small such that

$$P + \langle \boldsymbol{u} \cdot \nabla q \rangle = \langle q \partial_p \omega \rangle = -\langle \omega \partial_p q \rangle$$

Therefore, depletion δ **when accounting for the impacts of advection** is given by:

$$\begin{aligned} \delta &= \left(\frac{P_h + \langle \boldsymbol{u} \cdot \nabla q_h \rangle}{(P + \langle \boldsymbol{u} \cdot \nabla q \rangle) \cdot \mathrm{SMOW}} - 1 \right) \\ &= \left(\frac{\langle \omega \partial_p q_h \rangle}{\langle \omega \partial_p q \rangle \cdot \mathrm{SMOW}} - 1 \right) \end{aligned}$$

A key assumption that links p_ω to δ is that $\partial_p q_h$ and $\partial_p q$ can be taken to be constant on a time-averaged basis. However, ***we have found that this assumption may not hold true in small regions***.

Methodology and Datasets

Region of Interest

Our region of interest lies in the eastern Pacific and the southwest Caribbean, spanning 90-75ºW and 0-15ºN, coinciding with the flight paths of the OTREC2019 field campaign (Fuchs-Stone et al., 2020).

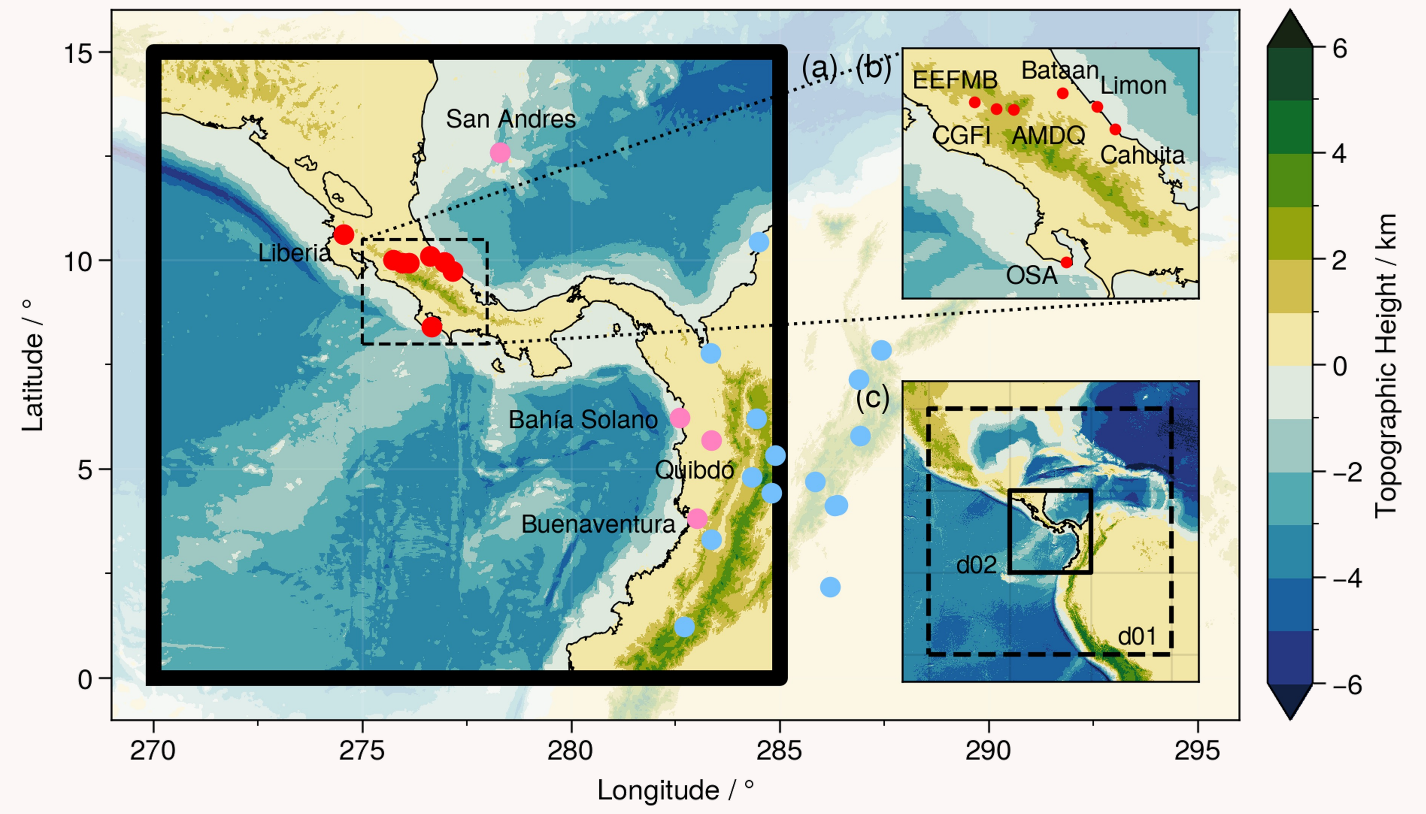


*Figure 2: We display here the region of interest which mirrors the OTREC2019 field campaign. In (a), we denote in red and pink the meteorological stations in Costa Rica and Colombia respectively that provided isotopic precipitation data at near-daily frequency; (b) shows a close-up of the inland Costa Rica stations and the complex topography in the region; (c) shows the boundaries of the nested domains **d01** and **d02** in our WRF modelling setup, with 9km and 3km horizontal-resolution respectively.*

Observational Datasets

- Station rainfall data at **near-daily frequency** in Costa Rica and Colombia, with **HDO and $H_2^{18}O$ depletion**
  - Validated against GPM IMERGv6 half-hourly data (Huffman et al., 2020)
  - Costa Rica stations valid from 2019 Jul-Dec
  - Colombia stations largely valid from 2019 Jul – 2021 Jun

- ERA5 Reanalysis, pressure-velocity winds ω at Pressure Levels 10-1000 hPa, for calculation of p_ω
  - Monthly data 1979-2021 for p_ω climatology (Fig. 1)
  - Hourly data from 2019 Jul to 2021 Jun, used to calculate 7-day and 30-day moving averages of p_ω

WRF Model Setup

- Isotope-enabled version WRF-ARW v3.9.1 (Skamarock et al., 2008)
  - Exchanges of HDO and $H_2^{18}O$ implemented in microphysics scheme of Thompson et al. (2008)
  - see Moore et al. (2016) and Blossey et al. (2010) for more details

- Experimental Setup:
  - 5 months model time, from 0000 UTC 31 July to 0000 UTC 31 December 2019
  - Two nested domains, **d01** and **d02** (Fig. 2c), of 9 and 3 km horizontal grid spacings respectively
  - Cumulus parameterization **only for d01 domain** (d02 is cloud-permitting)

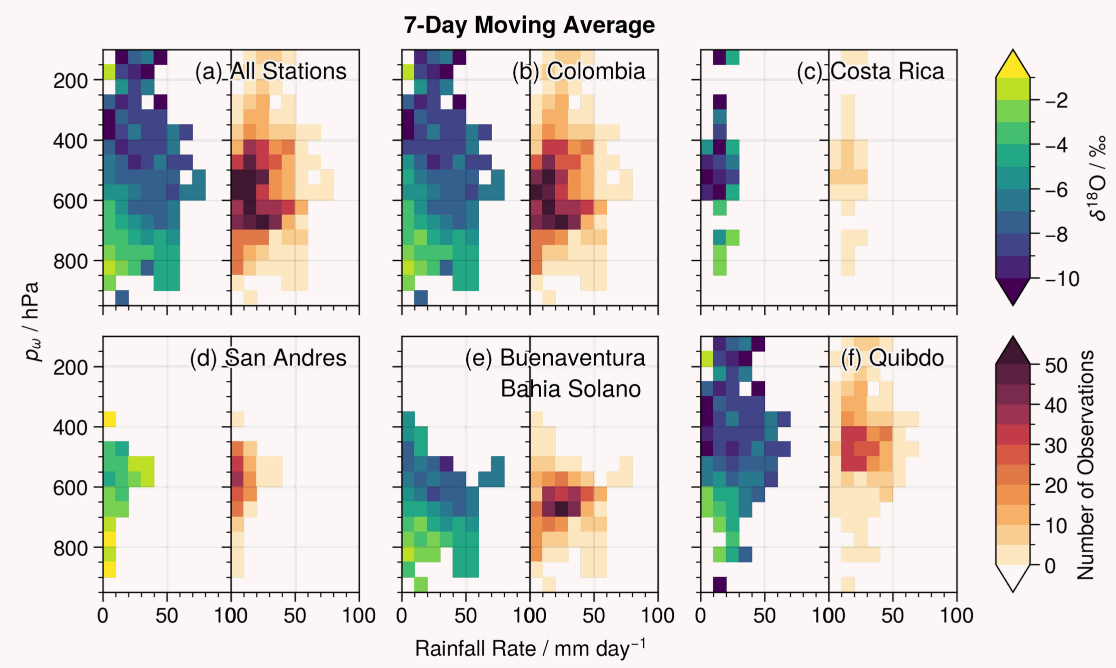
- Simulations driven using ERA5 Reanalysis (Hersbach et al., 2020) fields
  - Nudging applied above boundary layer every 6 hours

Conclusion and Future Work

Our composite results are similar to Torri et al. (2017). However, ***as we breakdown our composites into individual localities***, we find that these trends may not apply.

By ***accounting for the impacts of advection*** $\langle \boldsymbol{u} \cdot \boldsymbol{\nabla q} \rangle$ on isotopic depletion, we are largely able to reduce the differences between localities. However, this only applies if we can assume that the time-averaged $\partial_p q_h$ and $\partial_p q$ are invariant. Otherwise, accounting for the impacts of advection show no visible trend.

Results



Station Observations and ERA5 Reanalysis

- **Depletion of heavy isotopes $\boldsymbol{\delta} \uparrow$ as $\boldsymbol{p_\omega} \downarrow$** (i.e., as the convective heating profile becomes more top-heavy)
- Amount effect () is significant

- Composite results line up nicely with those of Torri et al., (2017)
  - However, stations over **mainland Colombia** dominate composite
  - **Is it possible to generalize this composite** to the whole OTREC domain as opposed to just mainland Colombia?

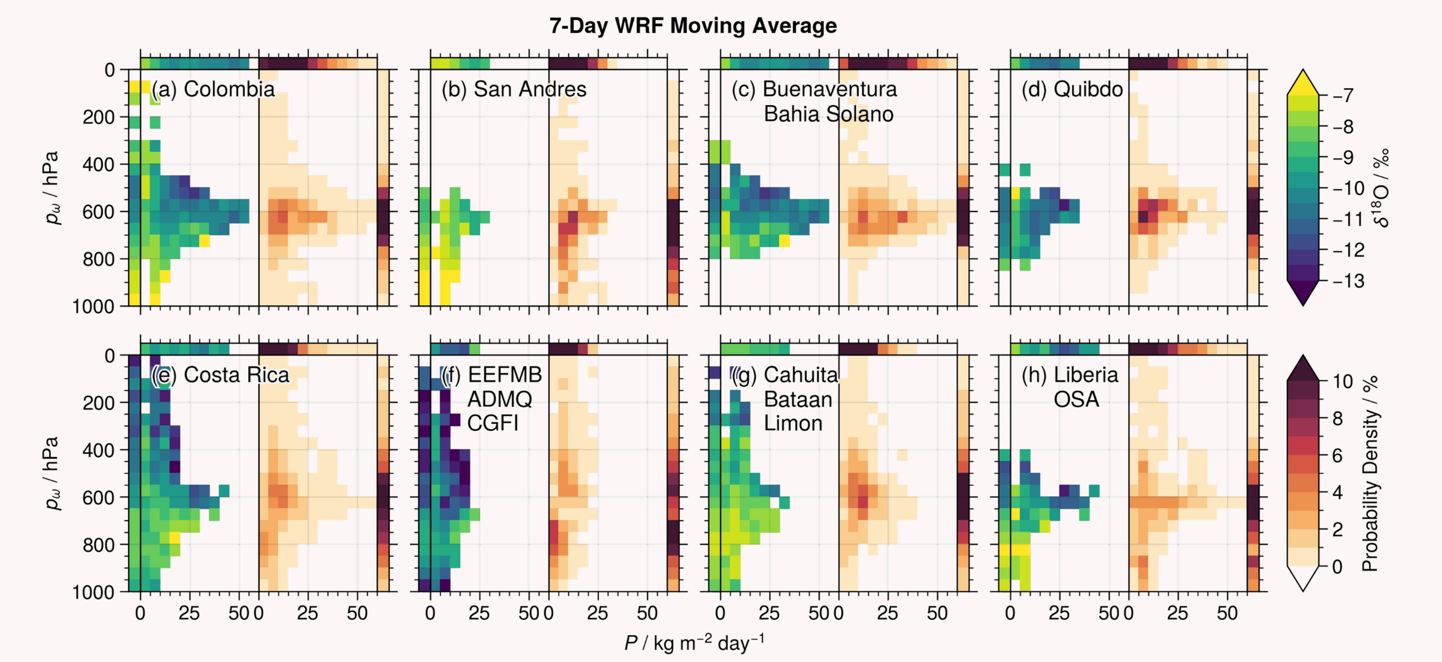
- Depletion in heavy isotopes in precipitation over San Andres are **different compared to mainland Colombia**.
  - Climatology of San Andres is noticeably different
  - Trends might be different with different climatology

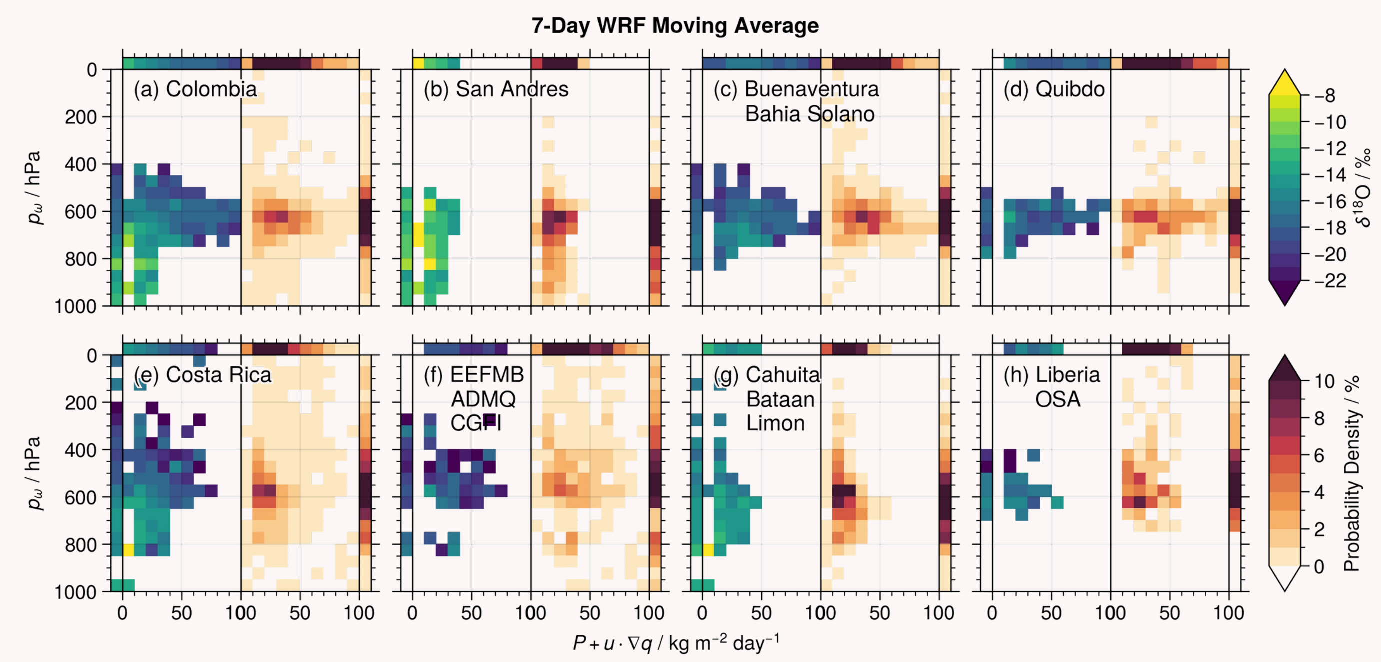
WRF Modelling

- Overall trends are similar to observations
  - WRF model results are **more depleted**

- Same as in observations, **trends of depletion are different depending on location**
  - Stations in central Costa Rica are more depleted than other locations
  - San Andres is much less depleted than other stations

- Can these differences be attributed to **differences in local advection** $\langle \boldsymbol{u} \cdot \nabla q \rangle$ in different parts of the domain?

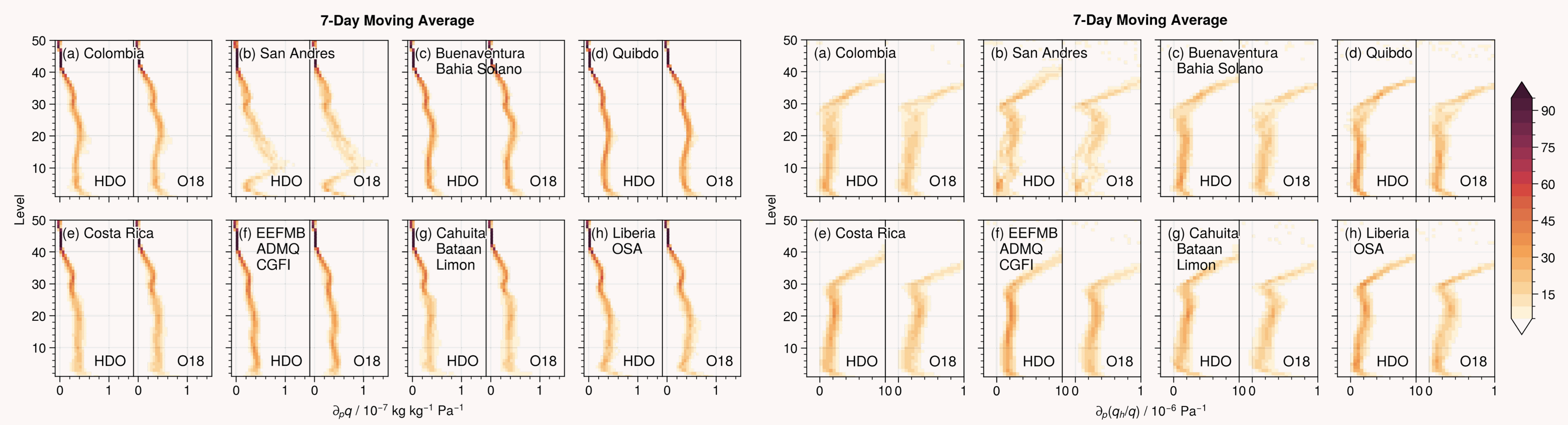




Accounting for Impacts of Advection

- Stations on the coast of the Pacific basin tend to be more depleted compared to stations on the coast of the Atlantic basin
  - **Depletion of heavy isotopes $\boldsymbol{\delta} \uparrow$ as $\boldsymbol{p_\omega} \downarrow$** remains evident over most stations
  - **No consistent relationship between $\boldsymbol{\delta}$ and $\boldsymbol{p_\omega}$** for a given $P + \langle \boldsymbol{u} \cdot \nabla q \rangle$ is observed over San Andres

- Implies that the fundamental assumption that $\partial_p q_h$ and $\partial_p q$ are invariant over time for every region **does not hold**



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