ISOLATING THE THERMODYNAMIC RESPONSE OF TROPICAL CONVECTION TO COLUMN MOISTURE

Hrag Najarian and Matthew R. Igel*
University of California Davis

1. Introduction

In the tropics, the relationship between column relative humidity and precipitation is straightforward. With an increasing amount of moisture present in the atmospheric column, the rate of precipitation increases exponentially above a given threshold, approximately 77% (**figure 1a,b,c**) (Bretherton et al., 2004; Rushley, S. S., Kim, D., Bretherton, C. S., and Ahn, M.-S., 2018; Ahmed, F., and C. Schumacher, 2015).

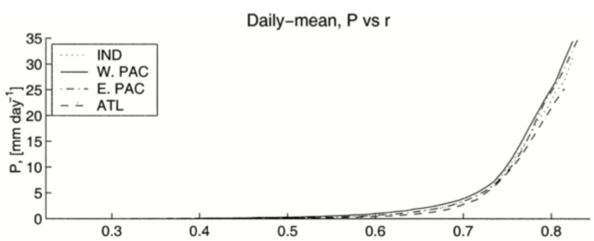

Figure 1a - Bretherton et al. (2004) shows the relationship of precipitation and relative humidity (r) in different parts of the tropics using SSM/I satellites (version 5).

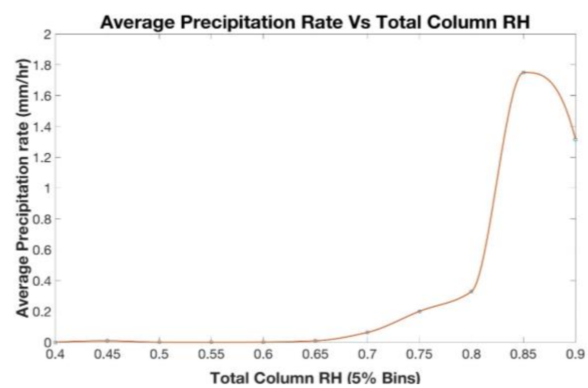

Figure 1b - Hrag Najarian and Matthew R. Igel observations indicate the exponential growth in precipitation with increased column <RH> in 5% binned sections located in the Maldives.

* *Corresponding author address:* Matthew R. Igel, Univ. of California, Department of Land, Air, and Water Resources, Davis, CA 95616; e-mail: migel@ucdavis.edu.

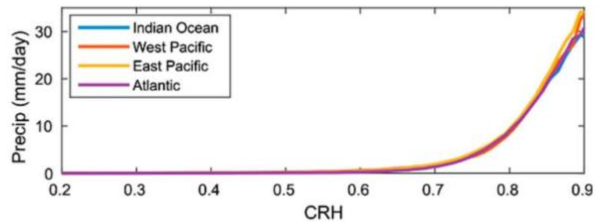

Figure 1c - Rushley, S. S., Kim, D., Bretherton, C. S., and Ahn, M.-S. (2018) used SSM/I satellite data (version 7) in order to present the relationship of column <RH> (CRH) with Precipitation rate across tropical regions.

However, "CRH is not a single factor that governs precipitation over tropical oceans", atmospheric dynamics also plays a significant role (Bretherton 2018). The analysis put forward describes the mechanisms used to study the influence moisture has on tropical precipitation without the underlying influence large-scale circulation has on mean precipitation rates.

2. Data and Methods

The DYNAMO field campaign conducted in the Indian Ocean in 2011 produced over seven-hundred radiosonde launchings from the Maldives spaced 3 hours apart from one another, with data being relayed back every 2 seconds until the eventual demise of the balloon. The data collected from these soundings were initially used to corroborate a theory introduced from a model that posited that tropical moisture above and below the freezing level act quasi-independently. Igel (2017) considers splitting the tropical atmosphere into two logical moisture layers which ultimately allows for more precise precipitation rate predictions while also predicting clouds type formations. Unfortunately, it was concluded that DYNAMO soundings did not provide enough data to conduct a definitive test of their result. After this impediment, the idea to input the sonde data into a cloud resolving model began to seem promising as a way help compare sonde data with the simulations in Igel (2017).

Utilizing the Regional Atmospheric Modeling System (RAMS), a cloud resolving model with advanced physical parameterizations, we simulated deep convective environments by applying constant surface convergence. We first took the over seven-hundred soundings and, extracted column humidity (<RH>), pressure, and temperature layer data, excluding any wind data. We then used these variables to initialize RAMS simulations. Artificial surface convergence lasted the full hour for each simulation. Crucially, using convergence to excite convection instead of inserting a warm air bubble kept the integrity of the atmosphere's thermodynamics. This constant convergence value was meticulously calibrated by simulating the sounding with the highest observed precipitation rate and ensuring RAMS simulated a reasonably similar precipitation rate. Once we settled on an appropriate/ideal value of constant convergence, it was then applied to the rest (>700) of the tropical soundings. After analyzing the simulated data, one major distinction between observational and model data became apparent.

3. Results

Observational data has always indicated that with a linear increase in <RH>, mean precipitation rate increases exponentially (**figure 1**). However, with an increase in <RH>, precipitation rate increased linearly according to our simulated results (**figure 2**). Previously in the introduction, we mentioned that precipitation is not only dependent on moisture availability, but many other contributing factors. We accept that atmospheric dynamics is a secondary contributing factor in tropical precipitation prediction, along with moisture availability. Large-scale dynamics was kept constant due to a fixed convergence value, leaving precipitation rates solely dependent on the changes in moisture availability, <RH>, which in turn led to the conclusion stated above. In other RAMS setups which include the moisture-dynamics feedback, precipitation has been observed to increase exponentially. Therefore, we are left to conclude that without largescale dynamics impacting rainfall, precipitation rate has a linear dependence on moisture availability in the tropics.

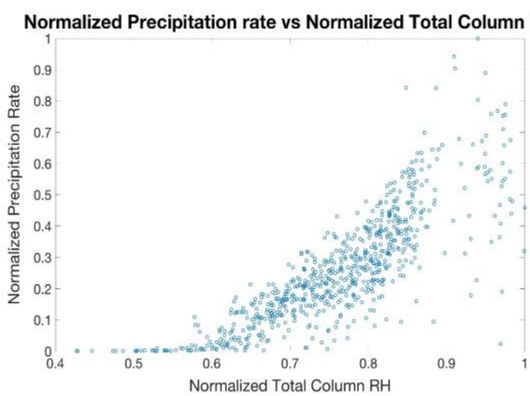

Figure 2 - Normalization is defined as dividing by the largest data point in each axis; **Y-axis max: 340mm/hr**, **X-axis max: 95%**. This figure shows that with an increase in column <RH>, we notice more of a linear growth, well after the ~77% mark.

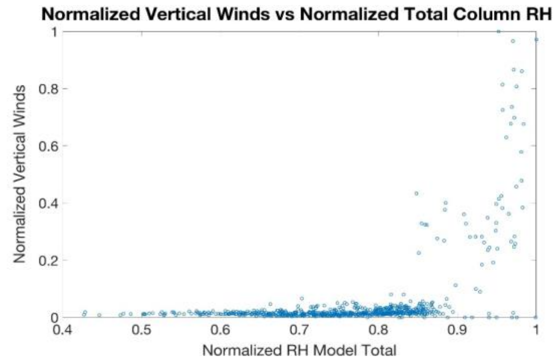

Figure 3 - Simulations >85% see higher than average vertical winds, hindering the actual precipitation rate.

4. Summary and Future Work

In previous observational studies, mean precipitation from ground observations, satellites, and full physics models increased exponentially with increasing column <RH>. However, in these simulations, the mean precipitation rate grew linearly with increasing column <RH>. The only variable that differed between the observation and model investigations was the absence of large-scale dynamics in the simulation. By subjecting every simulation to a constant surface convergence, we ultimately divorced large-scale dynamics from <RH>. This led us to discover a linear trend in precipitation rates with an increase in column <RH>.

However, there is still much more work that needs to be done in order to be sure of this declaration. Simulations must run longer than an hour for cases where column <RH> surpassed ~85%. This is due to significant vertical updrafts present in the systems after 60 minutes keeping precipitation rates from reaching their maximum potential value (**figure 3**). The precipitation rates observed versus the precipitation rates simulated were substantially elevated due to the nature of forced convergence, therefore we must also revisit initializing the constant value used in RAMS to produce more realistic precipitation rates.

This is the first step in understanding the complex and intertwined relationship dynamics and thermodynamics has on precipitation rates. By identifying the potential impact dynamics has on precipitation rates, we have set a foundation on which continued investigations may be built to further our understanding of the sensitivity of precipitation to moisture. By proceeding, we will better understand how variables such as convection and precipitation will respond to thermodynamic and dynamic forcing's and how they work together.

5. References

Ahmed, F., and C. Schumacher (2015), Convective and stratiform components of the precipitation-moisture relationship, Geophys. Res. Lett., 42, 10,453–10,462, doi:10.1002/2015GL066957.

Bretherton, C. S., Peters, M. E., & Back, L. E. (2004). Relationships between water vapor path and precipitation over the tropical oceans. Journal of Climate, 17, 1517–1528.

Igel, M. R., S. R. Herbener and S. M. Saleeby (2017), The tropical precipitation pickup threshold and clouds in a radiative convective equilibrium model: 1. Column moisture, J. Geophys. Res. Atmos., 122, doi:10.1002/ 2016JD025907.

Rushley, S. S., Kim, D., Bretherton, C. S., & Ahn, M.-S. (2018). Reexamining the nonlinear moisture-precipitation relationship over the tropical oceans. Geophysical Research Letters, 45, 1133–1140. https://doi.org/10.1002/ 2017GL076296