3A.3 GROSS MOIST STABILITY ASSESSMENT: CONVECTIVE AMPLIFICATION AND DECAY

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1. INTRODUCTION

It is well known that tropical convection and column-integrated water vapor (aka precipitable water) are tightly related. Past work suggested there is a positive correlation between precipitation and precipitable water (Bretherton et al. 2004, and many others.) This moisture-precipitation relationship plays a key role in the interaction between convection and associated large-scale circulations in the tropics. Ensemble of subgrid-scale convection collectively alters large-scale circulations, and those large-scale circulations, in turn, change the local environment to be favorable or unfavorable for the convection via changing the local moisture condition.

For investigating this mutual relationship, column-integrated moist static energy (MSE) budgets have been proven to be useful. Because temperature anomalies are negligible in the deep tropics [weak temperature gradient approximation (WTG; Sobel et al. 2001)], the column MSE budgets approximately tell us about the processes associated with the growth and decay of precipitable water. Under the WTG, the column MSE budgets can be approximately written as:

$$\frac{\partial \langle Lq \rangle}{\partial t} \simeq -\nabla \cdot \langle h\mathbf{v} \rangle + \langle Q_R \rangle + S \qquad (1)$$

where $h \equiv s + Lq$ is MSE; s is dry static energy (DSE); L is the latent heat of vaporization; q is specific humidity; Q_R is radiative heating rate; S is surface fluxes; and the angle brackets represent mass-weighted column-integration.

In this study, we will claim that the behavior of Eq. 1 can be better understood by examining the gross moist stability (GMS; Neelin and Held 1987; Raymond et al. 2009), which is defined as:

$$\Gamma \equiv \frac{\nabla \cdot \langle h\mathbf{v} \rangle}{\nabla \cdot \langle s\mathbf{v} \rangle}. \qquad (2)$$

We will investigate the GMS in a novel approach, which reveals that the GMS assessment in convective disturbances is particularly beneficial because the GMS has capabilities of predicting the subsequent convective evolution. We will clarify how it can be so. This study is verification and extensions of the ideas proposed by Inoue and Back (2015).

2. DATA DESCRIPTION

In this study, we obtained all the column MSE budget terms from satellite-based products. From satellite views, we can observe all the terms in Eq. 1 except for the flux divergence of column MSE, $\nabla \cdot \langle h\mathbf{v} \rangle$, which was derived as a residual of the budget equation. Similarly, flux divergence of column DSE, $\nabla \cdot \langle s\mathbf{v} \rangle$, was also calculated as a residual of the DSE budget equation. We removed diurnal cycles and composited seasonality from all the variables, and those were regridded into 2°x2° grids by spatial average and linear interpolation.

We investigated the data arrays from four oceanic basins: the Indian Ocean (IO), the western Pacific (WP), the eastern Pacific (EP), and the Atlantic Ocean (AO). 8-yr-long daily data from 2000 to 2007 was examined in this study.

3. RESULTS AND DISCUSSION

3.1 *CONVECTIVE AMPLIFICATION AND DECAY*

Assuming the positive correlation between precipitation (P) and precipitable water, we have:

$$\frac{\partial P}{\partial t} \sim \frac{\partial \langle q \rangle}{\partial t}. \qquad (3)$$

This relation indicates the RHS of Eq. 1 is associated with amplification and decay of the convection. Although we can investigate Eq. 1 as it it, we divide it by $\nabla \cdot \langle s\mathbf{v} \rangle$ which represents intensity of the convection, converting the MSE budget equation into the efficiency equation:

$$\nabla \cdot \langle s\mathbf{v} \rangle^{-1} \frac{\partial \langle Lq \rangle}{\partial t} \simeq -(\Gamma - \Gamma_C) \qquad (4)$$

where

$$\Gamma_C \equiv \frac{\langle Q_R \rangle + S}{\nabla \cdot \langle s\mathbf{v} \rangle} \qquad (5)$$

which was named the critical GMS by Inoue and Back (2015), and $\Gamma - \Gamma_C$ was collectively called the drying efficiency which is a version of effective GMS. Equation 4 is beneficial because it is independent of the convective intensity so that we can

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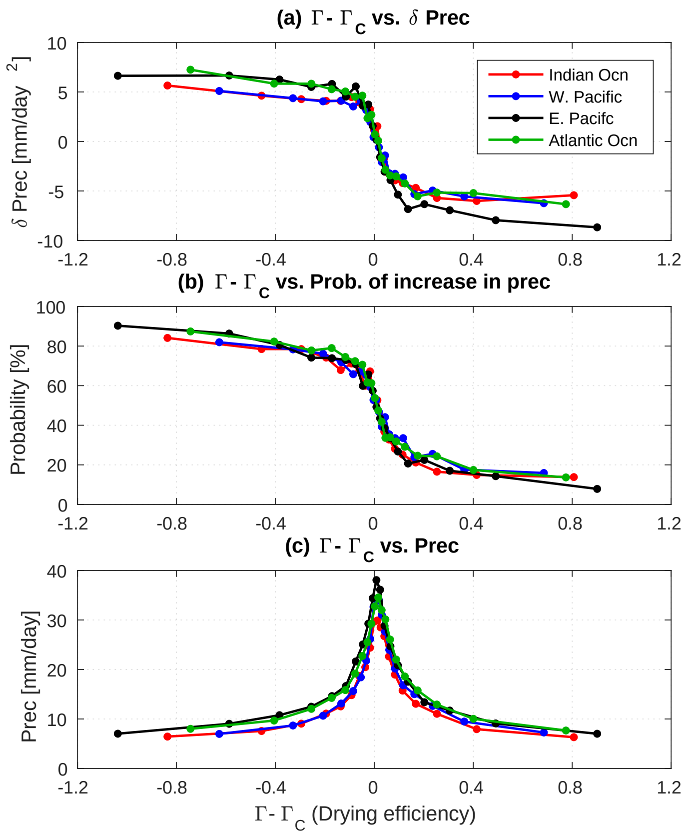

FIG. 1. (a) Binned precipitation changes, (b) binned probability of increase in precipitation, and (c) binned precipitation, as a function of $\Gamma - \Gamma_C$.

take composites of all convective events with different intensities.

According to Eqs. 3 and 4, we can separate convective life-cycles into two phases:

$$\Gamma - \Gamma_C < 0, \tag{6}$$

$$\Gamma - \Gamma_C > 0, \tag{7}$$

namely, the amplifying phase and the decaying phase, respectively. These relations are only the case when $\nabla \cdot \langle s\mathbf{v} \rangle$ is positive, and we will generalize this condition later by introducing the idea of "GMS plane".

First, we verified the ideas in Eqs. 6 and 7. Figure 1 shows, (a) precipitation change, (b) probability of increase in precipitation, and (c) precipitation, as a function of $\Gamma - \Gamma_C$, each of which was calculated by a binning method over the four different oceanic basins. Figure 1 verifies that when $\Gamma - \Gamma_C$ is negative/positive, the subsequent precipitation amplifies/decays at high probability, and when $\Gamma - \Gamma_C$ changes its sign, the phase abruptly switches, causing the maximum of precipitation. These patterns are quite universal among all the oceanic basins.

3.2 *GMS PLANE*

Now we generalize the idea of GMS by introducing the "GMS plane". First, we look at the relationship between diabatic forcing, $\langle Q_R \rangle + S$, and divergence of column DSE, $\nabla \cdot \langle s\mathbf{v} \rangle$, as in Fig. 2. As pointed out by Inoue and Back (2015), the diabatic forcing is positively correlated with $\nabla \cdot \langle s\mathbf{v} \rangle$. Therefore, as a first order approximation, we can express the diabatic forcing as:

$$F \equiv \langle Q_R \rangle + S = \gamma \nabla \cdot \langle s\mathbf{v} \rangle + \epsilon \tag{8}$$

where γ is some constant and ϵ is a random noise which is omitted from the following. Thus Eq. 1 can be approximated as:

$$\frac{\partial \langle Lq \rangle}{\partial t} \simeq -\nabla \cdot \langle h\mathbf{v} \rangle + \gamma \nabla \cdot \langle s\mathbf{v} \rangle. \tag{9}$$

According to Eq. 3, we have a relationship as:

$$\frac{\partial P}{\partial t} \sim -\nabla \cdot \langle h\mathbf{v} \rangle + \gamma \nabla \cdot \langle s\mathbf{v} \rangle. \tag{10}$$

This relationship can be illustrated in Fig. 3 where probability of convective amplification is plotted as

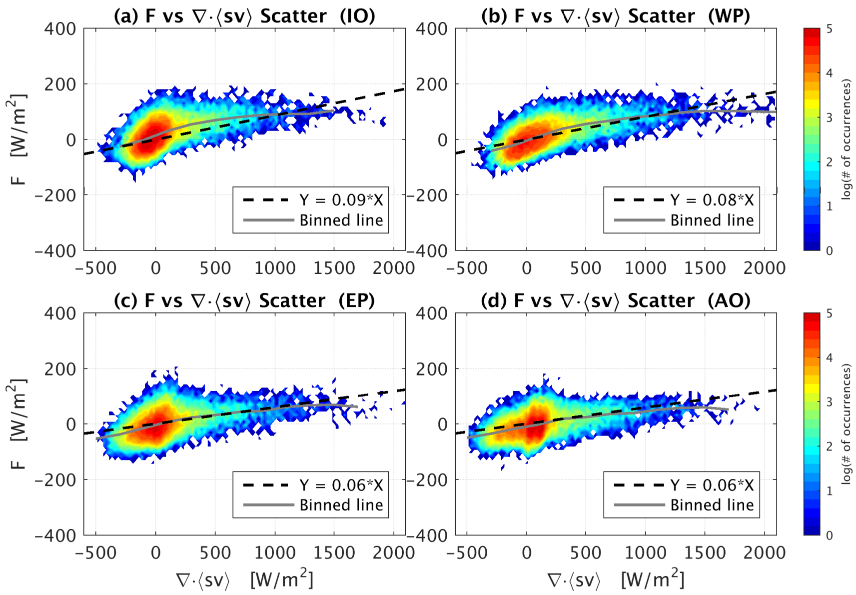

FIG. 2. 2-D histograms of the number of occurrences in log scale of the diabatic forcing and divergence of column DSE over the four different oceanic basins: the Indian Ocean (IO), the western Pacific (WP), the eastern Pacific (EP), and the Atlantic Ocean (AO).

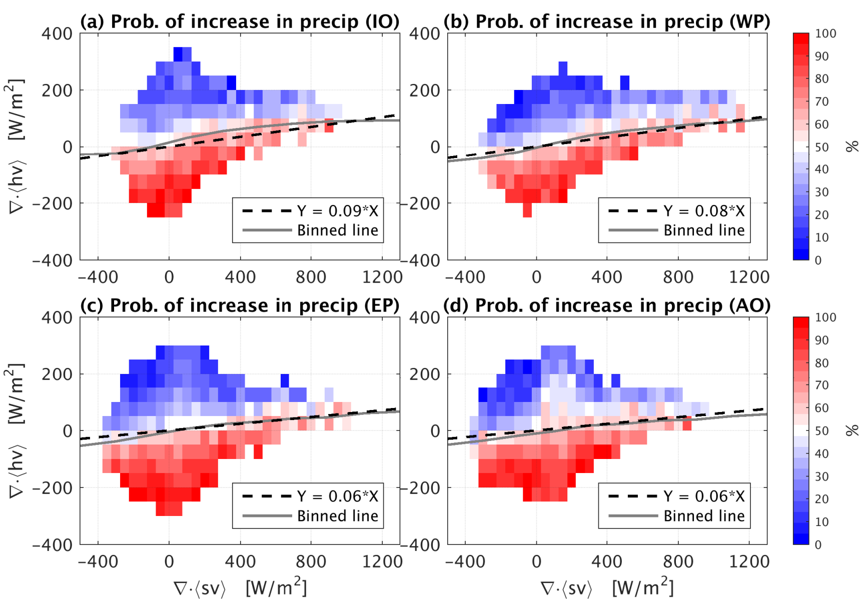

FIG. 3. Probability of increase in precipitation within the grid of $\nabla \cdot \langle h\mathbf{v} \rangle$ and $\nabla \cdot \langle s\mathbf{v} \rangle$ over the four different oceanic basins.

colored shade in the plane of $\nabla \cdot \langle h\mathbf{v} \rangle$ vs. $\nabla \cdot \langle s\mathbf{v} \rangle$, which we call the "GMS plane". The reddish/bluish color corresponds to convective amplification/decay, respectively. Obviously, if a data point lies below/above the dash line whose slope is γ, the convection tends to amplify/decay. When $\nabla \cdot \langle s\mathbf{v} \rangle$ is positive, those conditions are equivalent to Eqs. 6 and 7 with $\Gamma_C \simeq \gamma$.

More interestingly, we found that this GMS plane acts like a phase plane. Figure 4 shows mean changes of $\nabla \cdot \langle h\mathbf{v} \rangle$ and $\nabla \cdot \langle s\mathbf{v} \rangle$ as vector arrows on the GMS plane, which illustrates that convective lifecycles tend to orbit counter-clockwise around the critical GMS line (the dash line). This figure indicates that a position on the GMS plane (thus, a value of the GMS) has capabilities of predicting the

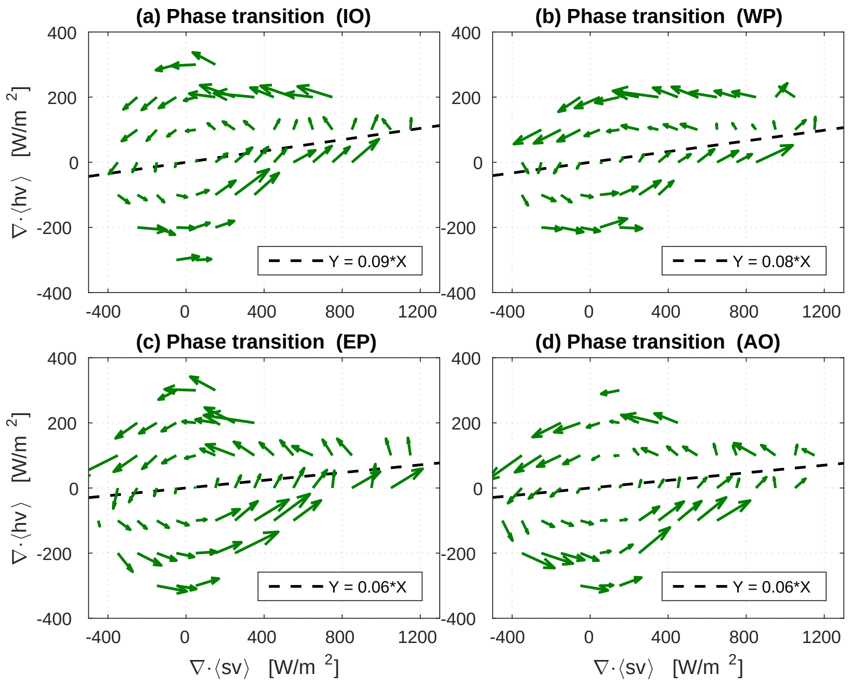

FIG. 4. Mean changes of $\nabla \cdot \langle h\mathbf{v} \rangle$ and $\nabla \cdot \langle s\mathbf{v} \rangle$ represented in vector arrows.

subsequent convective evolution as shown in the vector arrows.

4. CONCLUSIONS

We first showed that a value of $\Gamma - \Gamma_C$ predicts well the convective amplification and decay (Fig. 1). This idea was generalized by introducing the "GMS plane", which acts like a phase plane in which each convective life-cycle tends to orbit around the critical GMS line. This indicates a position on the GMS plane (i.e., a value of the GMS) has capabilities of predicting the subsequent convective evolution as shown in Fig. 4. We believe this phase-plane-like behavior is one of the main reasons why GMS is a useful diagnostic quantity.

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