The impact of vertical motion structure on the amplification of tropical convection

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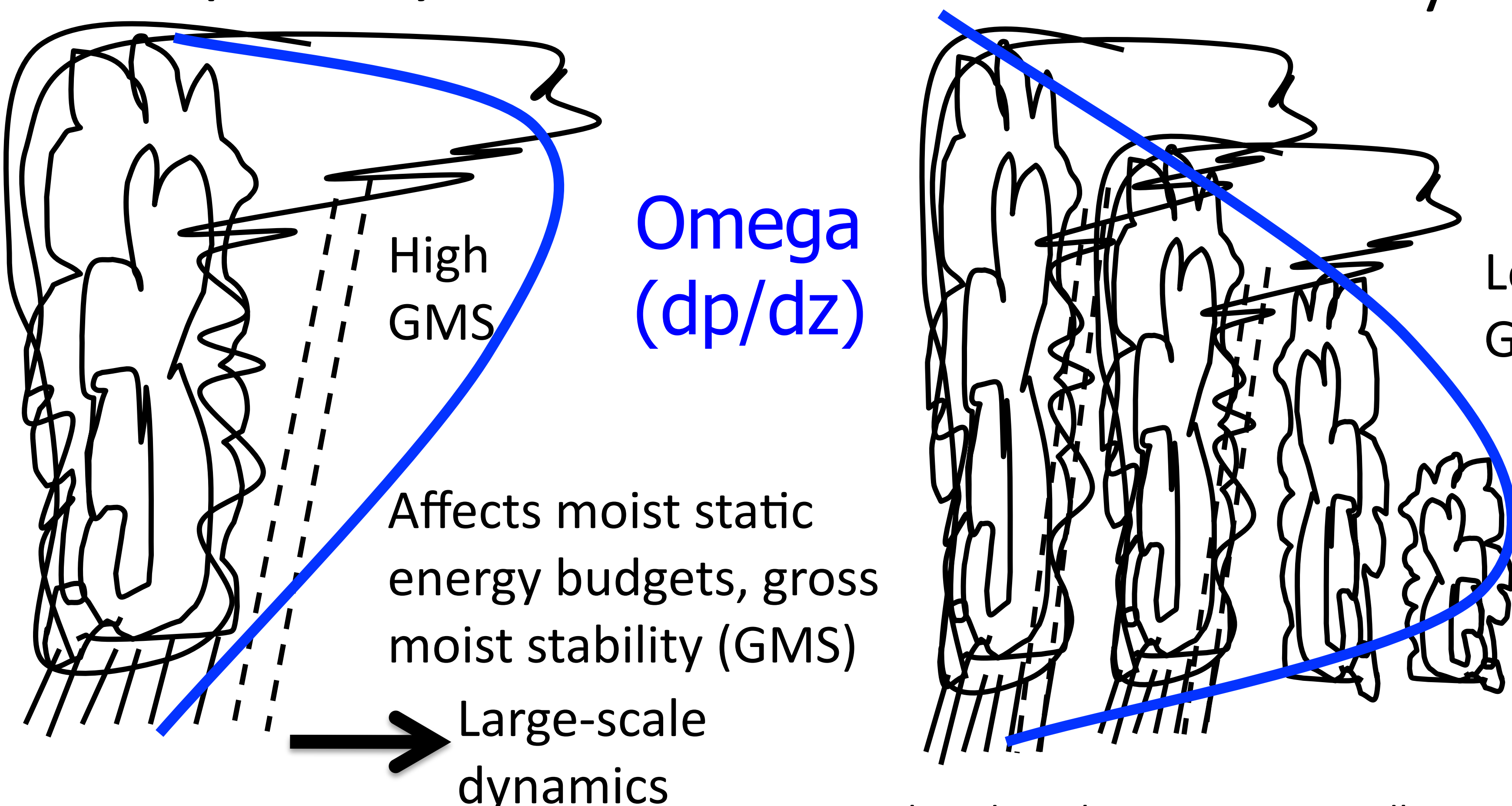
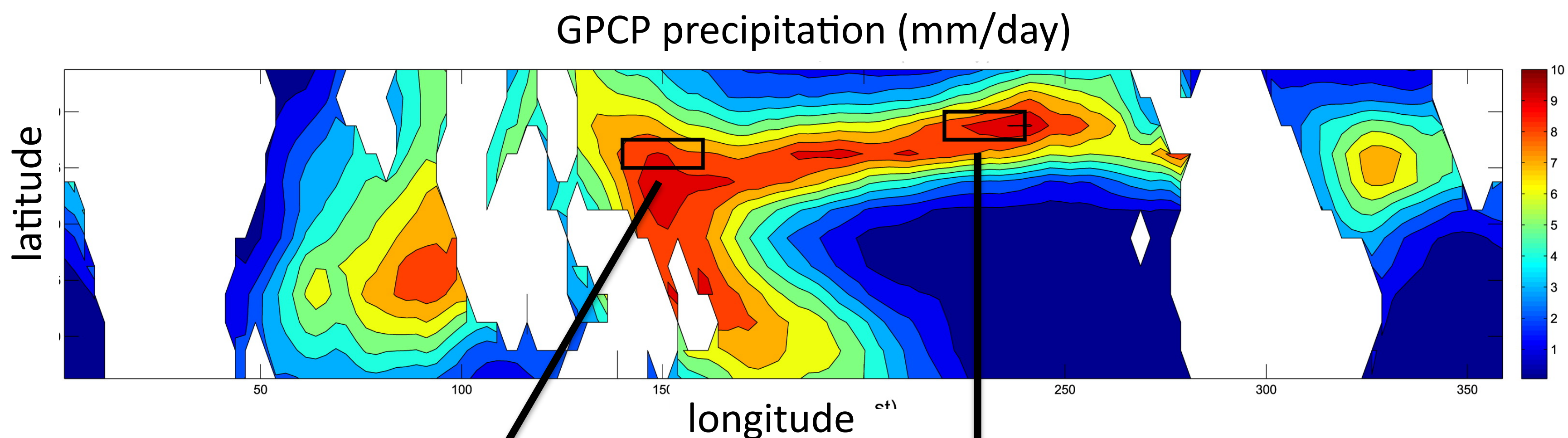
Vertical motion structures vary in space and time in the ITCZ

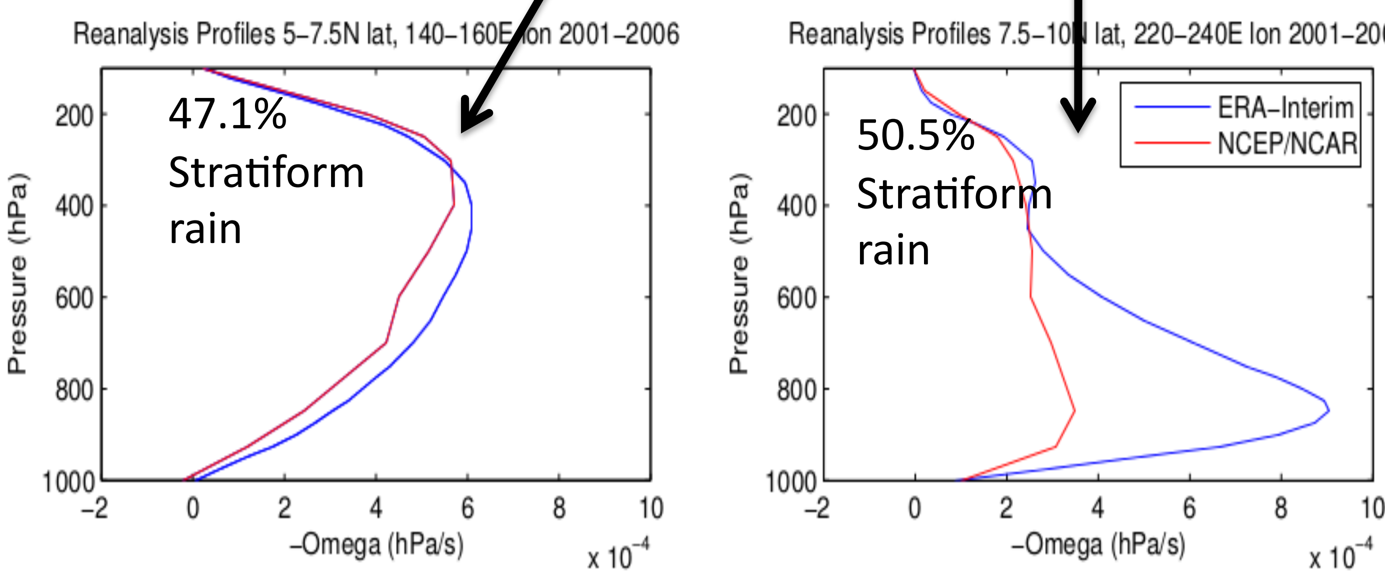
- Top-heavy
- Bottom-heavy



e.g. Back and Bretherton 2006, Handlos and Back 2014, Inoue and Back 2015a&b, many others

Geographic variability in mean vertical motion profiles due to effects of SST-gradients, relative SST,

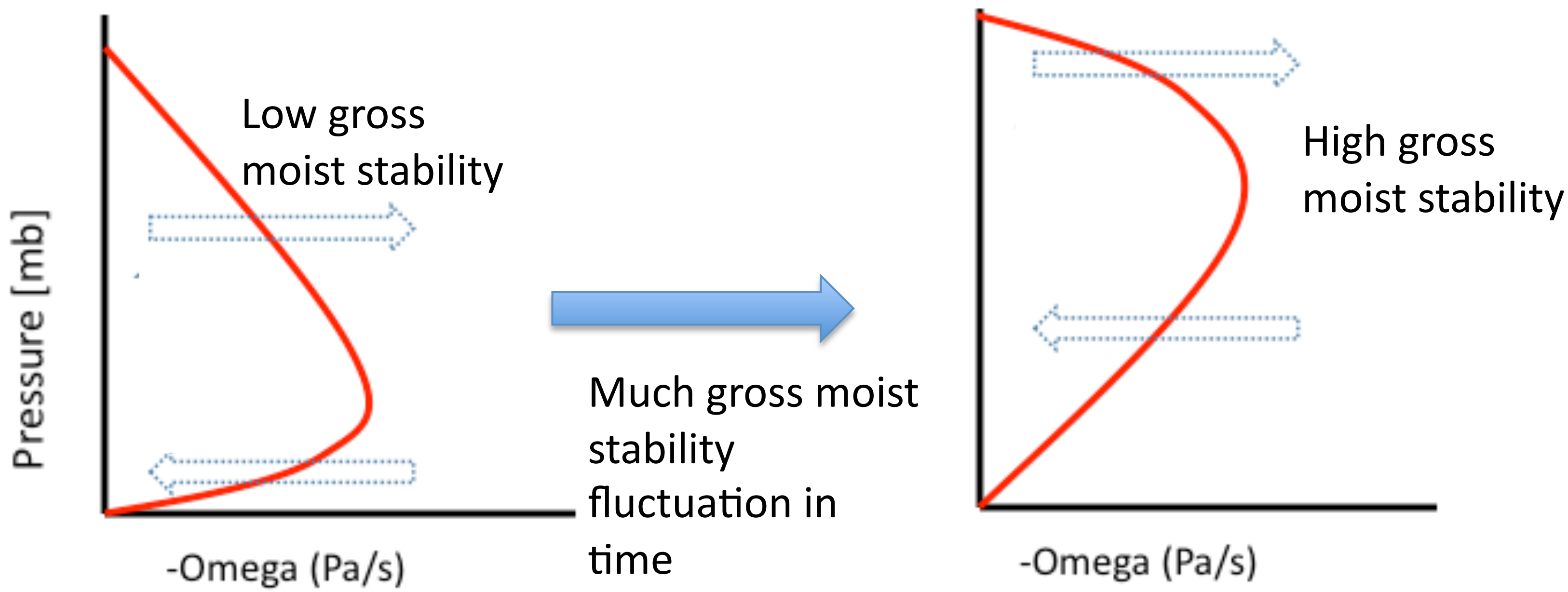




See Handlos and Back, 2014, poster here, Back and Bretherton 2009ab

Temporal variability of vertical motion profiles:

- During tropical deep convection, often observe bottom-heavy vertical motion profiles transitioning to top-heavy vertical motion profiles



- Thought to occur for range of timescales of variability
- Does this play a role in amplification/decay?
- What is appropriate value for comparing with theory?

Objectives:

- Investigate mechanisms of convective amplification and decay by analyzing the **gross moist stability (GMS)** $\Gamma \equiv \frac{\nabla \cdot \langle h\vec{v} \rangle}{\nabla \cdot \langle s\vec{v} \rangle}$
  - Sometimes convection "self-amplifies" via low GMS associated with bottom-heavy vertical motion profiles
  - Climatological GMS related to feedbacks between convection & radiation, evaporation

Normalize MSE budget terms by intensity → Gross Moist Stability (GMS)

$$-\left\langle \frac{\partial h}{\partial t} \right\rangle = -\left\langle -u\frac{\partial h}{\partial x} - v\frac{\partial h}{\partial y} \right\rangle - \left\langle -\omega \frac{\partial h}{\partial p} \right\rangle - LE - SH - \langle Q_r \rangle$$

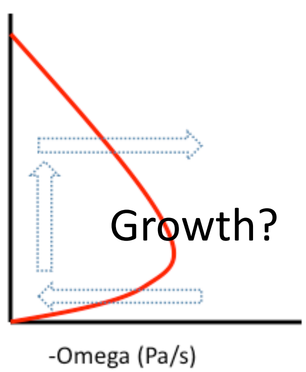
$$\nabla \cdot (s\vec{v})$$

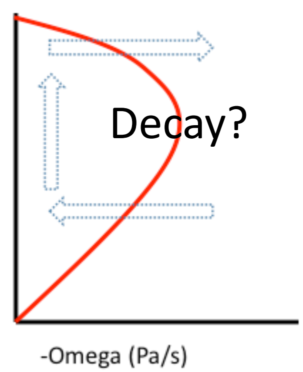
$$\Gamma = \Gamma_h + \Gamma_v \qquad -\Gamma_c$$

GMS describes efficiency of h export by horizontal, vertical motion

Effective GMS is $\Gamma - \Gamma_c$

Examine relationship to convective growth/decay during lifecycles

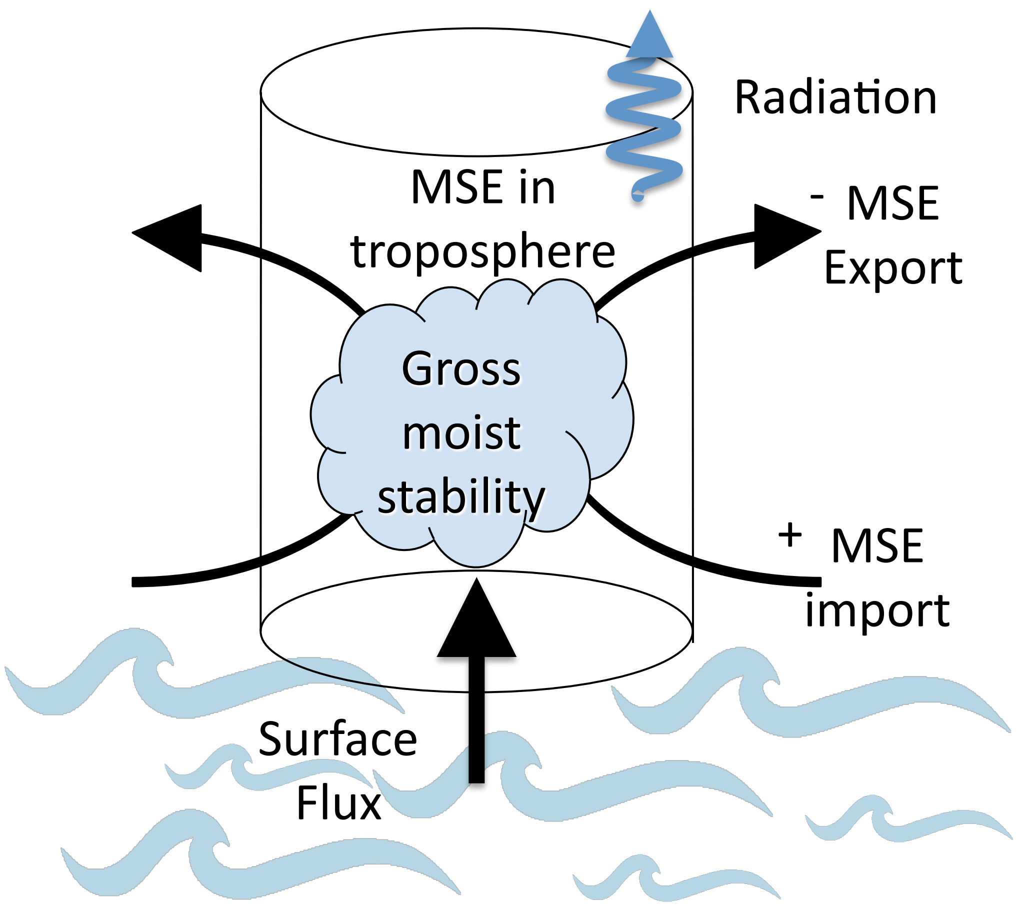




Can "predict" **Amplifying** and **Decaying** phases of event lifecycle using:

a) small temperature tendency

b) rain increases with column moisture



MSE Import > Export, Effective GMS < 0

$$\Gamma < \Gamma_C$$

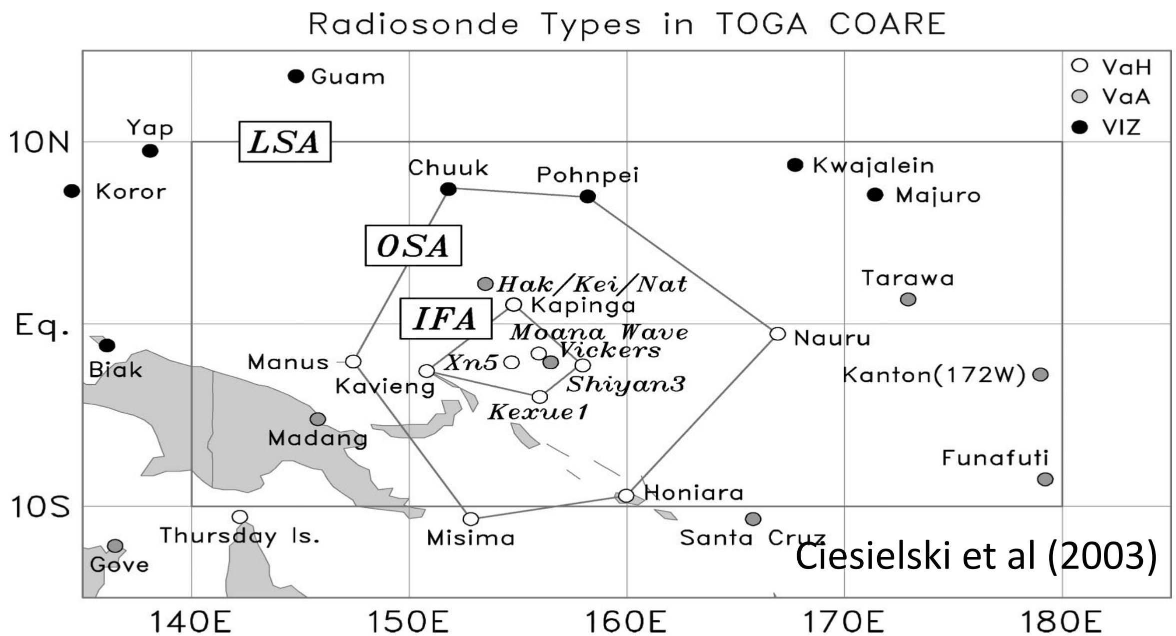
→

Amplification

$$\frac{\partial P}{\partial t} > 0$$

Similarly, *decay* for *positive effective GMS*

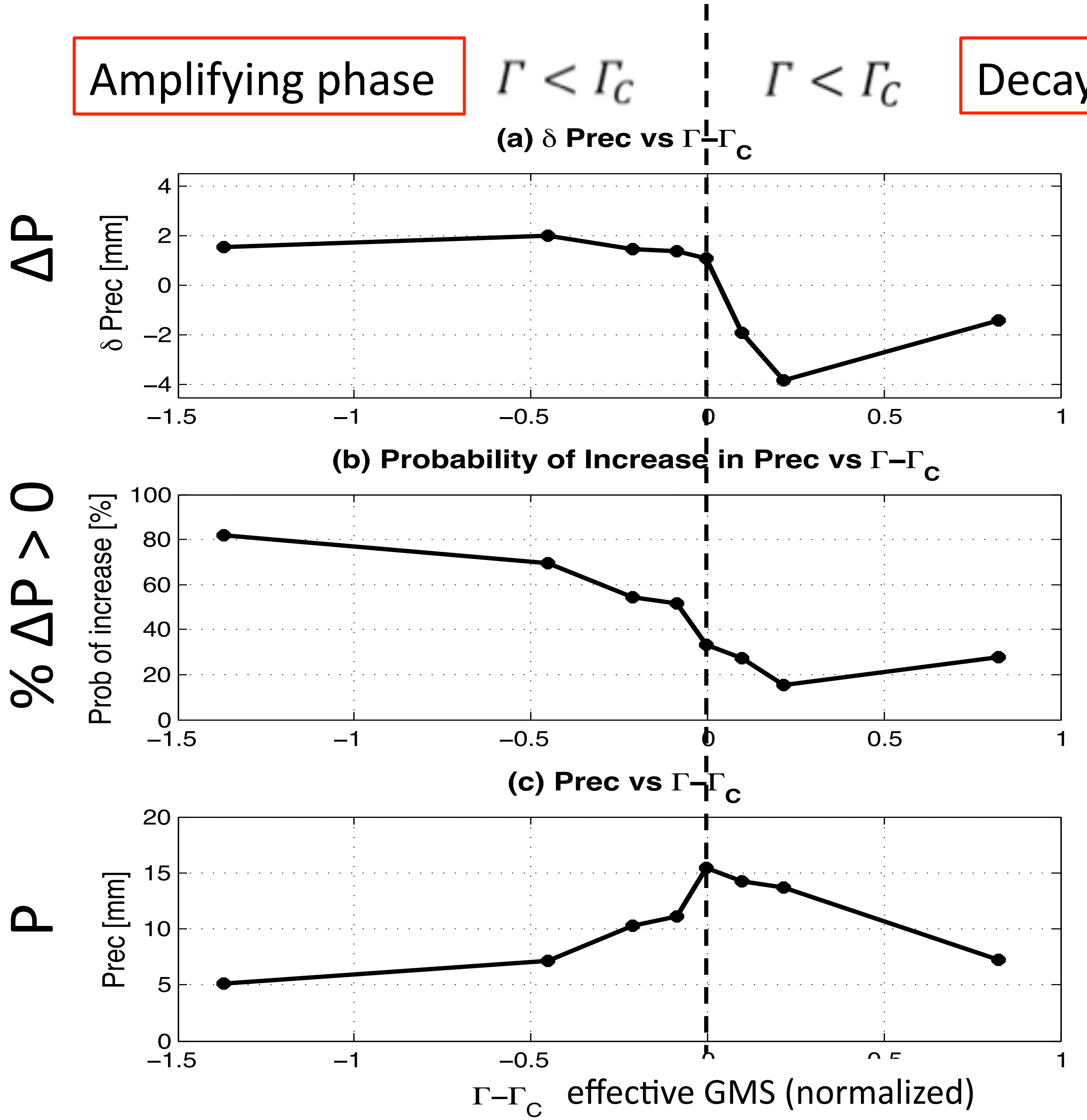
Test idea using Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE)



Ciesielski et al (2003)

- November 1992 through February 1993 (Intensive Observation Period)
- Domain:Intensive Flux Array (IFA)
- Data set constructed by Minghua Zhang (Zhang and Lin, 1997)

- Filter data to remove diurnal cycle (so T tendency small)
- Bin by an effective GMS (drying efficiency) Γ-Γ_c (for cases with denominator > 10 W/m^{2},)
- Examine frequency of precipitation increases, amount of precipitation increase

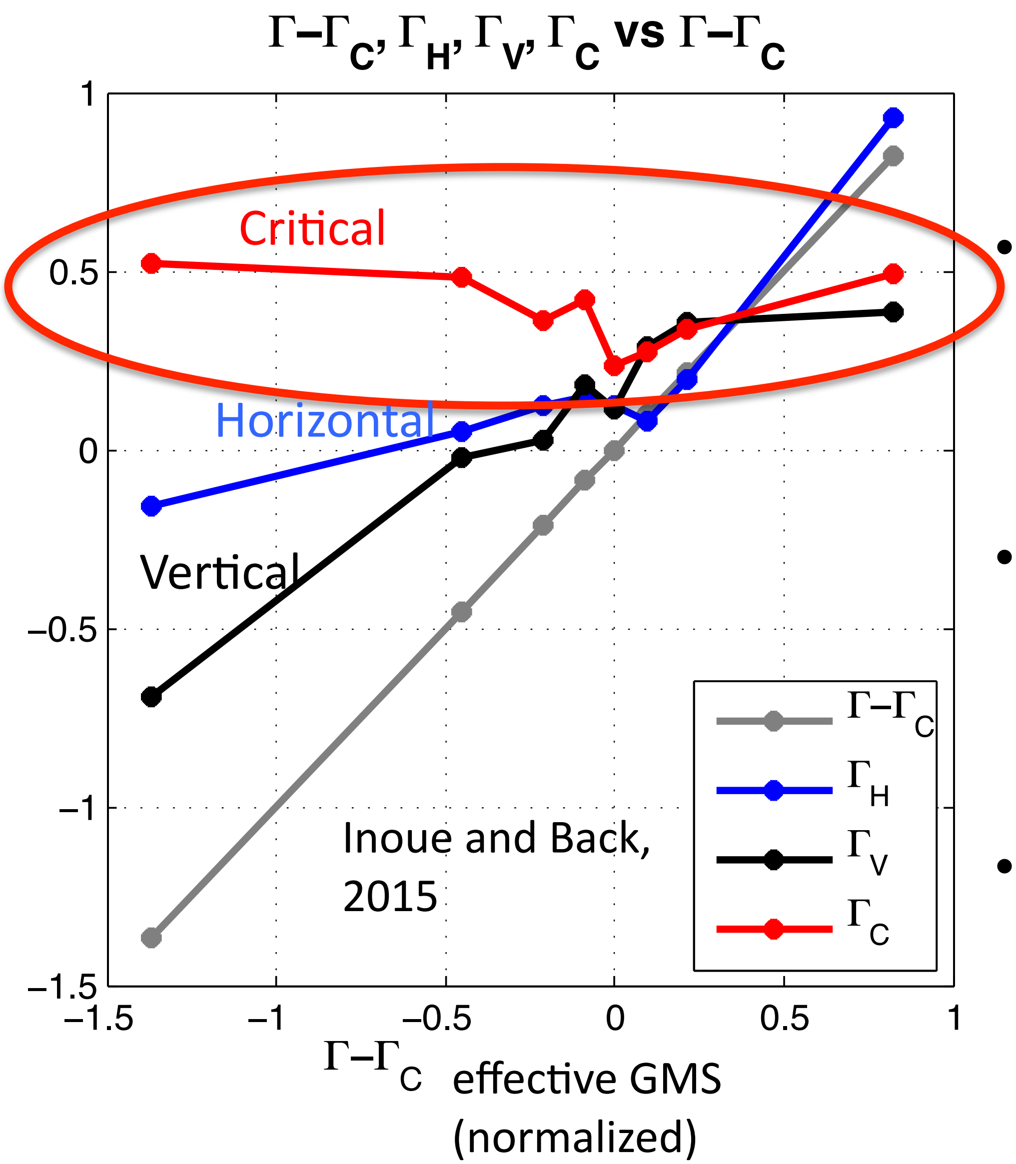


Low GMS associated with precipitation growth, high GMS associated with precipitation decay

GMS near-critical associated with high precip

Inoue and Back, 2015

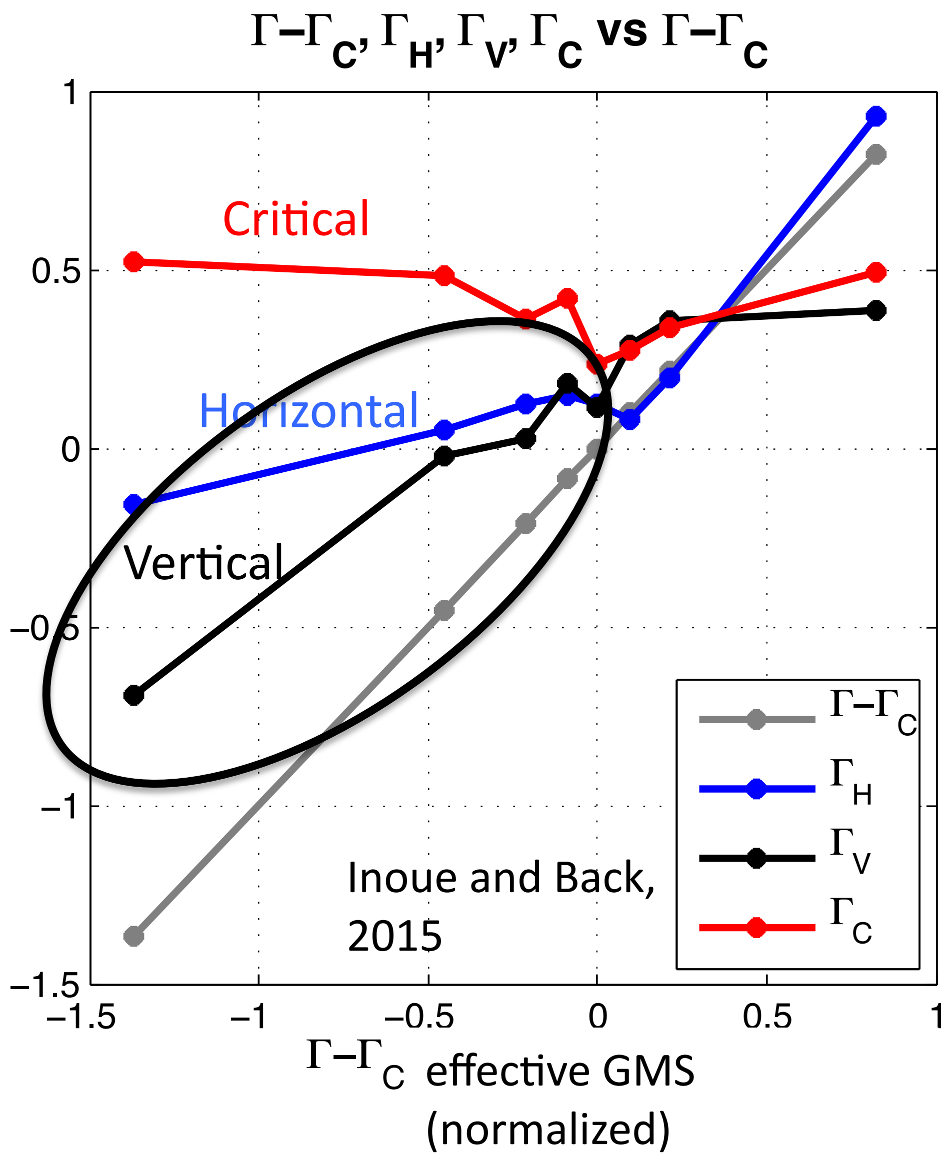
Critical GMS (associated with diabatic terms) relatively constant



$$\frac{\partial h}{\partial t} / \nabla \cdot (s\vec{v}) = \Gamma_v + \Gamma_h - \Gamma_c$$
$$= \Gamma - \Gamma_c$$

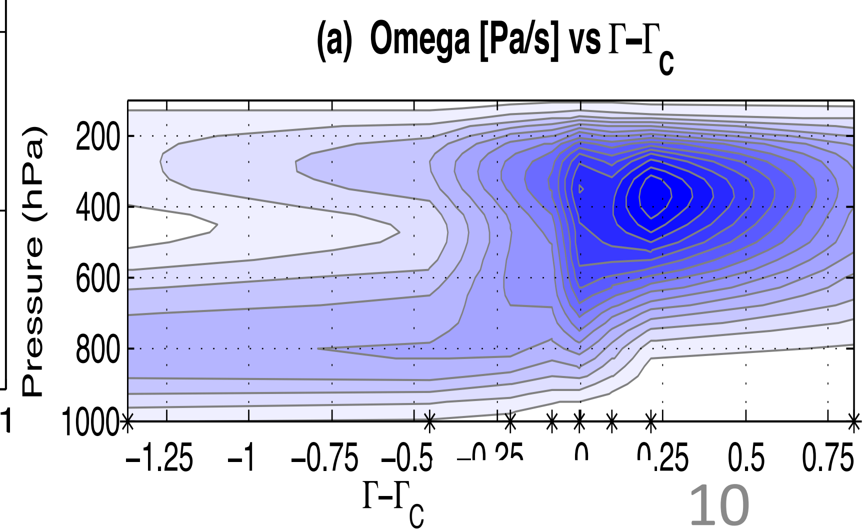
- Critical GMS is relatively constant in both amp/ decay phases (no a priori reason to expect)
- Radiation plus surface fluxes always tend to destabilize the convection by supplying MSE source
- Diabatic sources don't seem to regulate transition from growth to decay (timescale dependent?)

Vertical GMS explains variability in amplifying phase

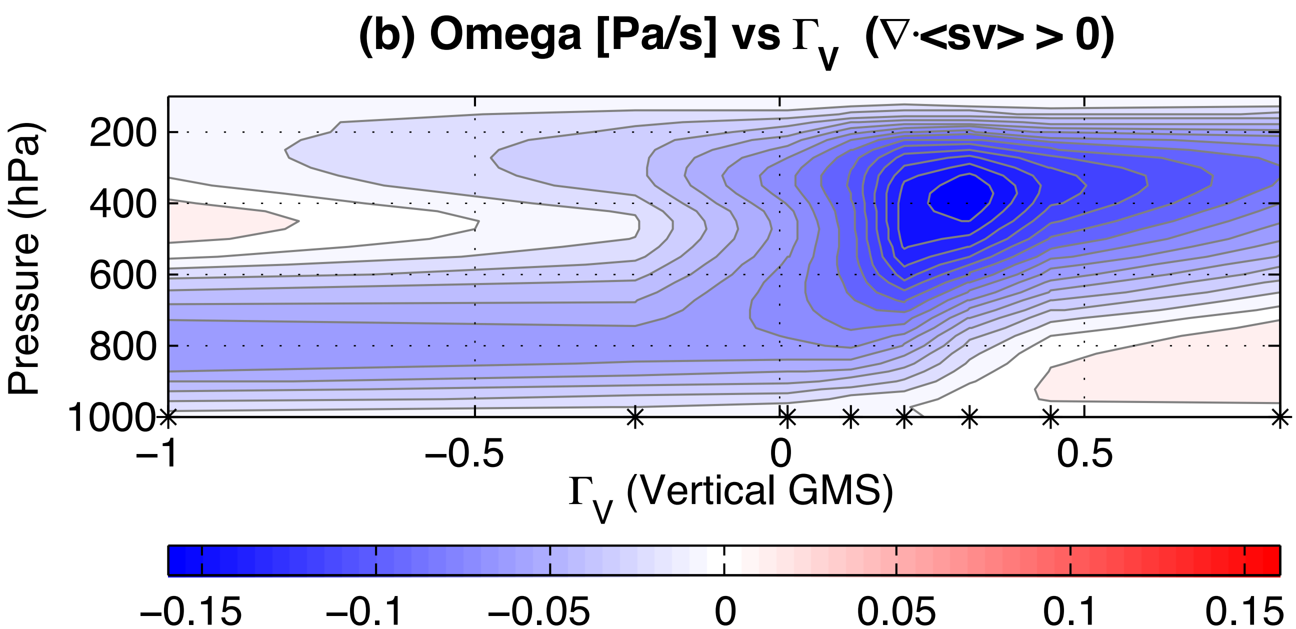


$$\frac{\partial h}{\partial t} / \nabla \cdot (s\vec{v}) = \Gamma_v + \Gamma_h - \Gamma_c$$
$$= \Gamma - \Gamma_c$$

In the amplifying phase, vertical GMS explains most of the variability of effective GMS



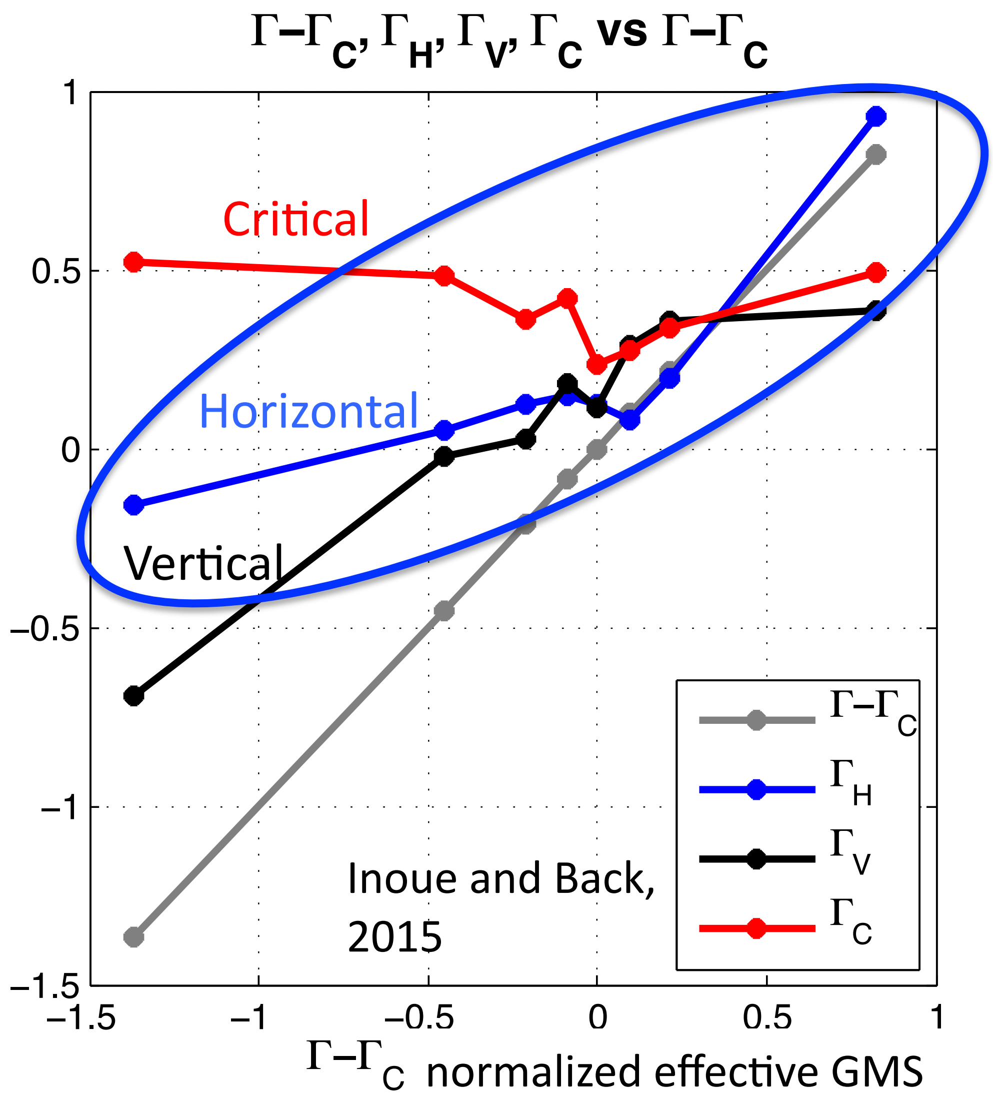
Vertical advection (& GMS) variations related to vertical motion profile shape



MSE *imported* by vertical motion

MSE *exported* by vertical motion

Horizontal GMS explains the variability in decaying phase

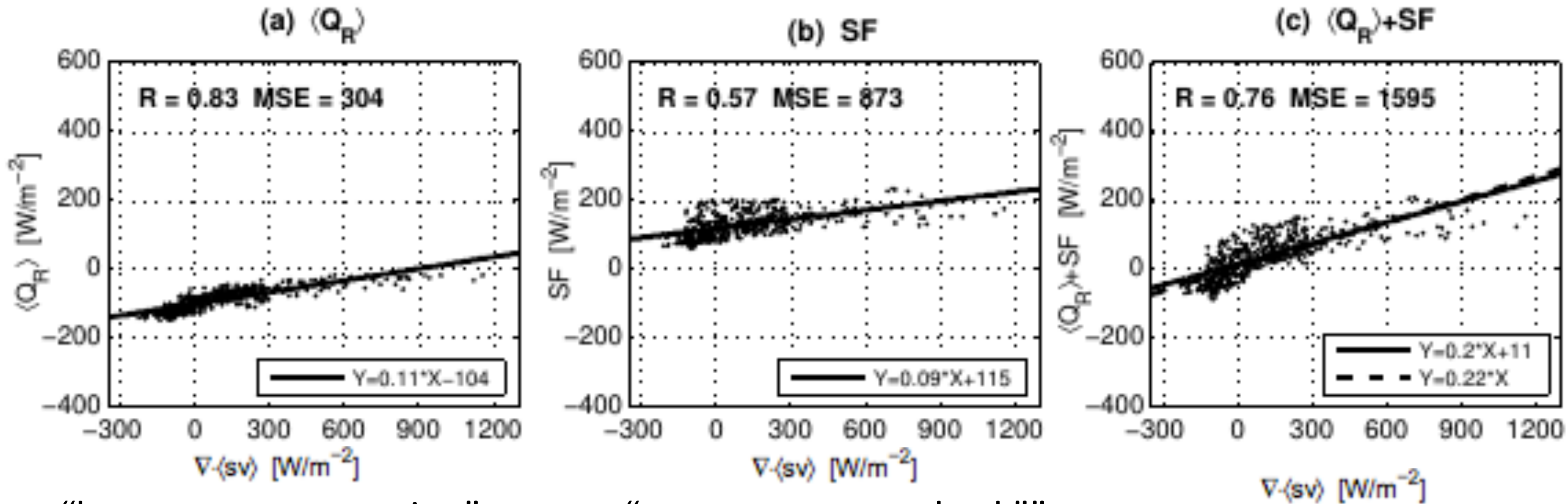


$$\frac{\partial h}{\partial t} / \nabla \cdot (s\vec{v}) = \Gamma_v + \Gamma_h - \Gamma_c$$
$$= \Gamma - \Gamma_c$$

In the decaying phase, horizontal GMS explains most of the variability of effective GMS

Indicates decaying is due to the horizontal advection (plus vertical advection)

Constant critical GMS associated with regression of radiative cooling plus evaporation on precipitation



"latent heat of radiation" "convergence feedback""

- This is a better fit than assuming constant gross moist stability

$$F \simeq \gamma \nabla \cdot \langle s\vec{v} \rangle. \qquad \Gamma_C \equiv \frac{F}{\nabla \cdot \langle s\vec{v} \rangle} \simeq \gamma.$$

Interpretation:

- Gross moist stability fluctuates around a critical (characteristic) value which is determined by relationship between convection and surface fluxes, radiative cooling

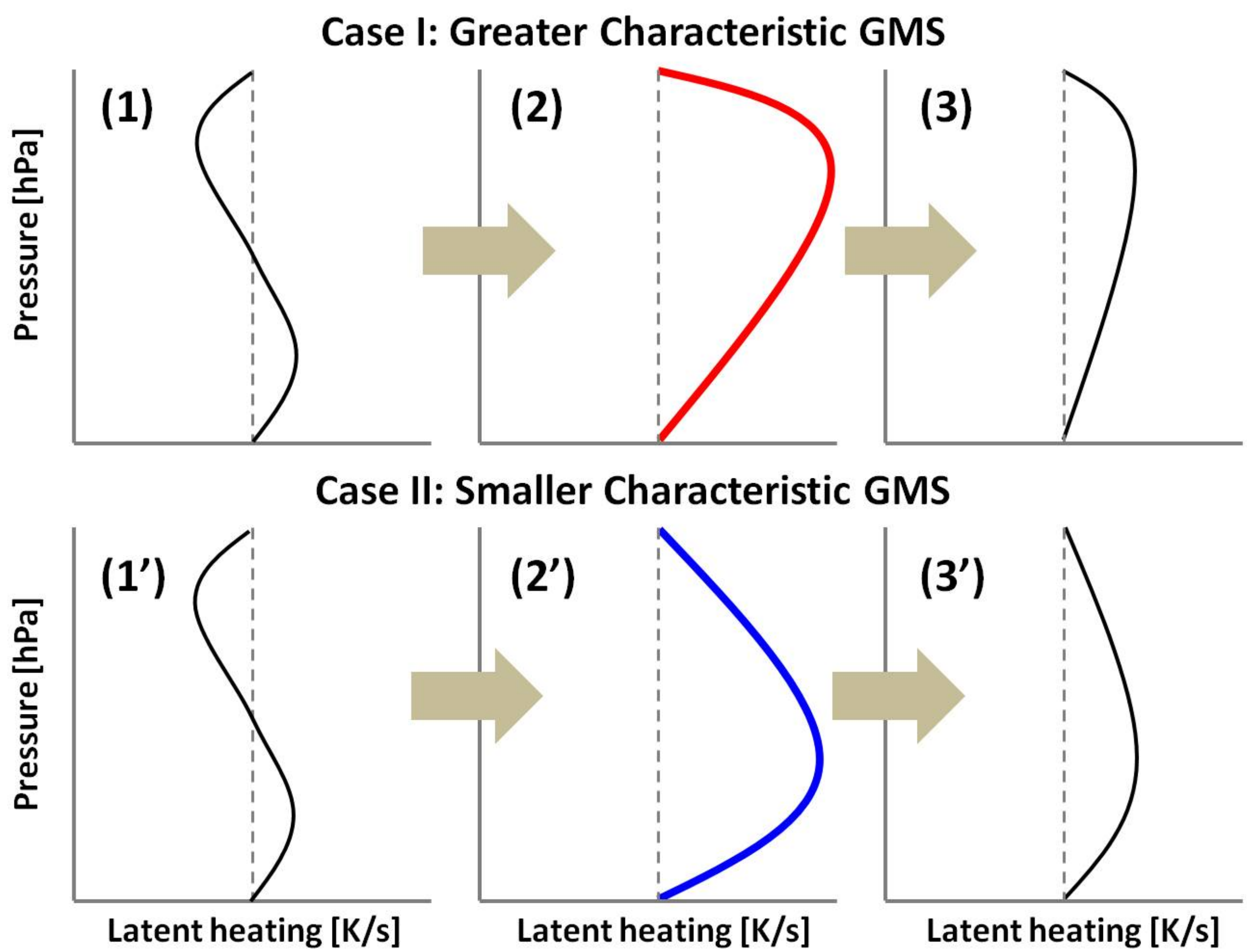
$$F \simeq \gamma \nabla \cdot \langle s\vec{v} \rangle. \qquad \Gamma_C \equiv \frac{F}{\nabla \cdot \langle s\vec{v} \rangle} \simeq \gamma.$$

$\Gamma - \gamma < 0$ Amplifying phase

$\Gamma - \gamma > 0.$ Decaying phase

- Feedbacks (radiative-convection and convergence) determine threshhold
- Characteristic GMS the one important for MJO, ITCZ-scale dynamics?

Gross moist stability fluctuations around a characteristic value?



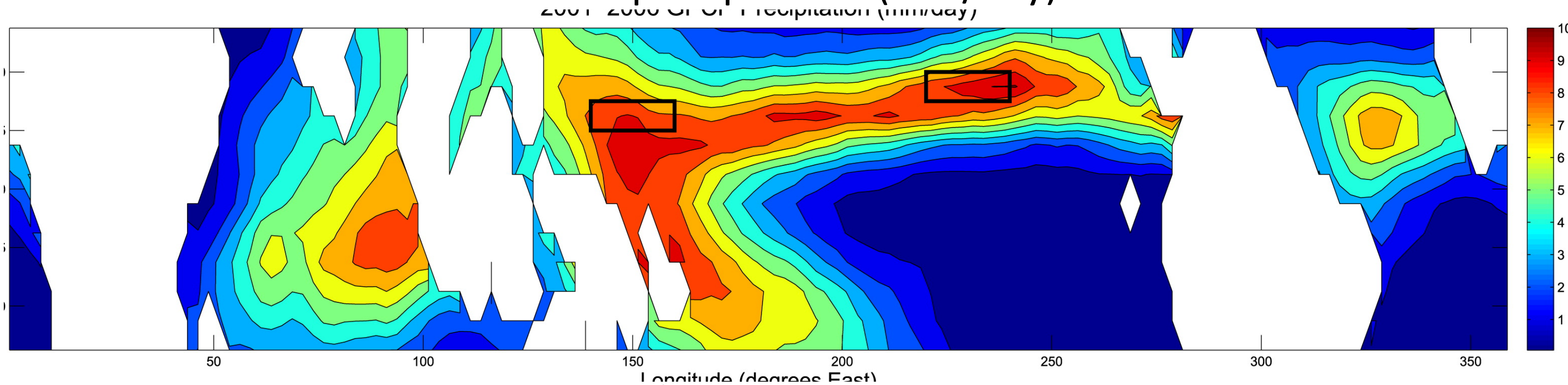
Like ITCZ regions without strong SST gradients?

Like ITCZ regions driven by strong SST gradients?

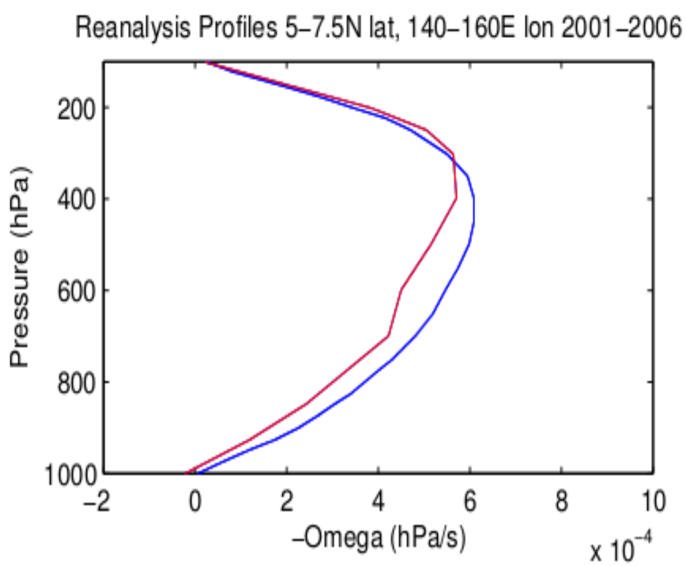
Variations in relationship between convection and radiative cooling, surface fluxes consistent with this

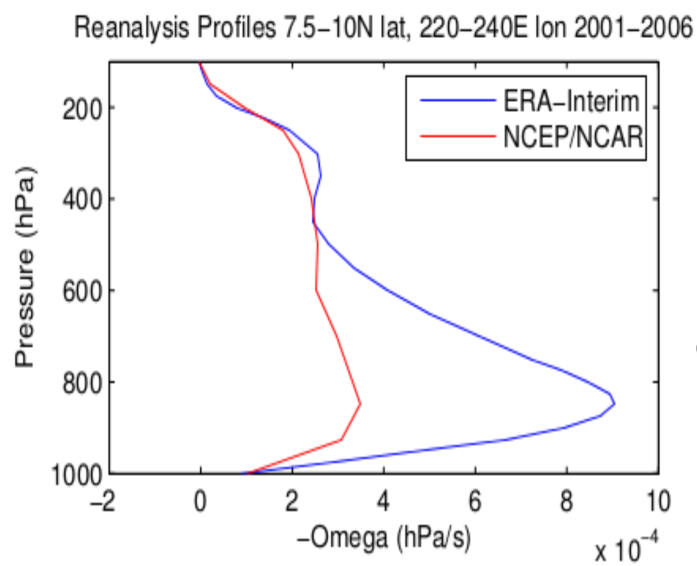
GPCP precipitation (mm/day)

latitude



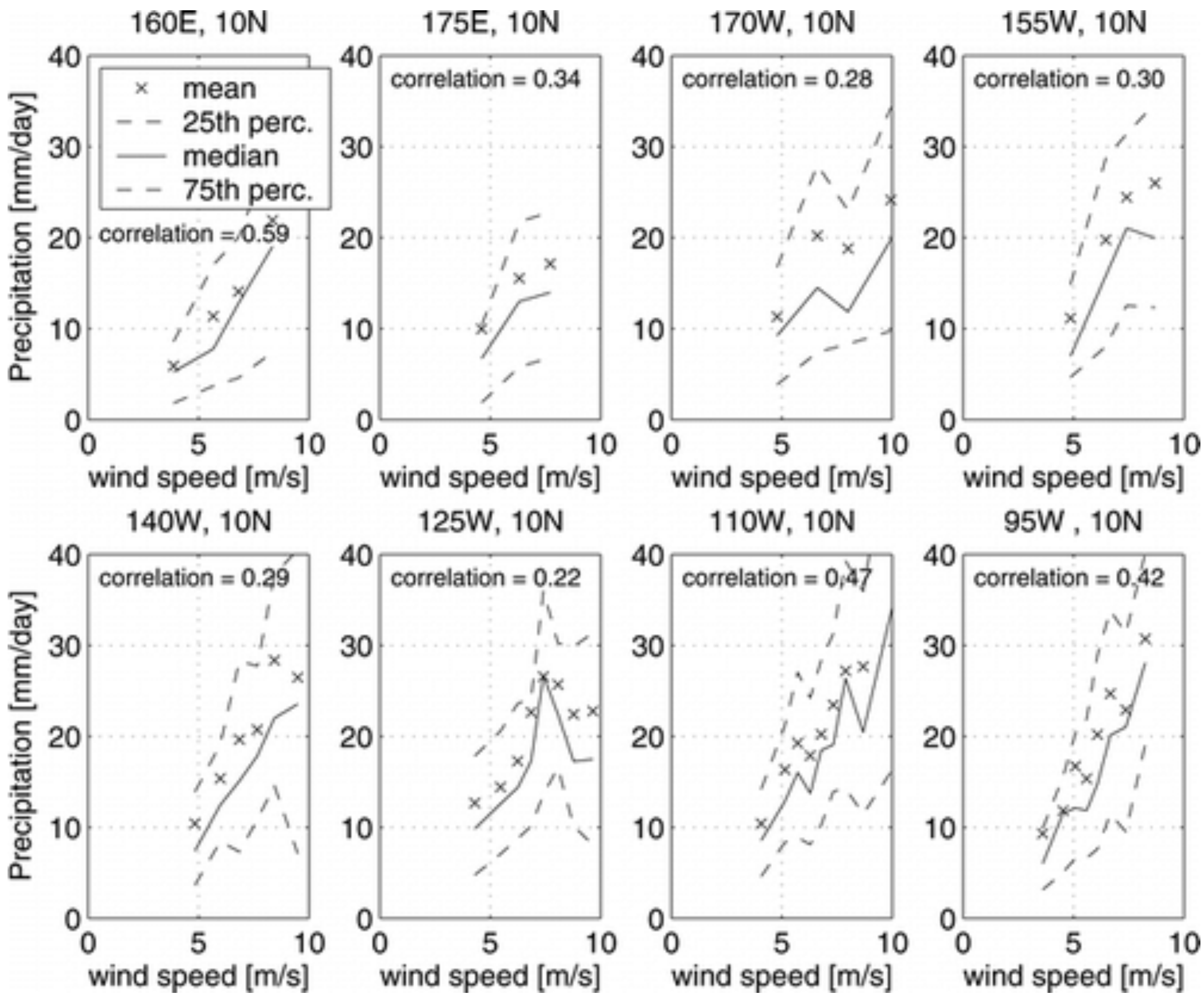
longitude





Radiative cooling reductions per unit precip depend on cloud height

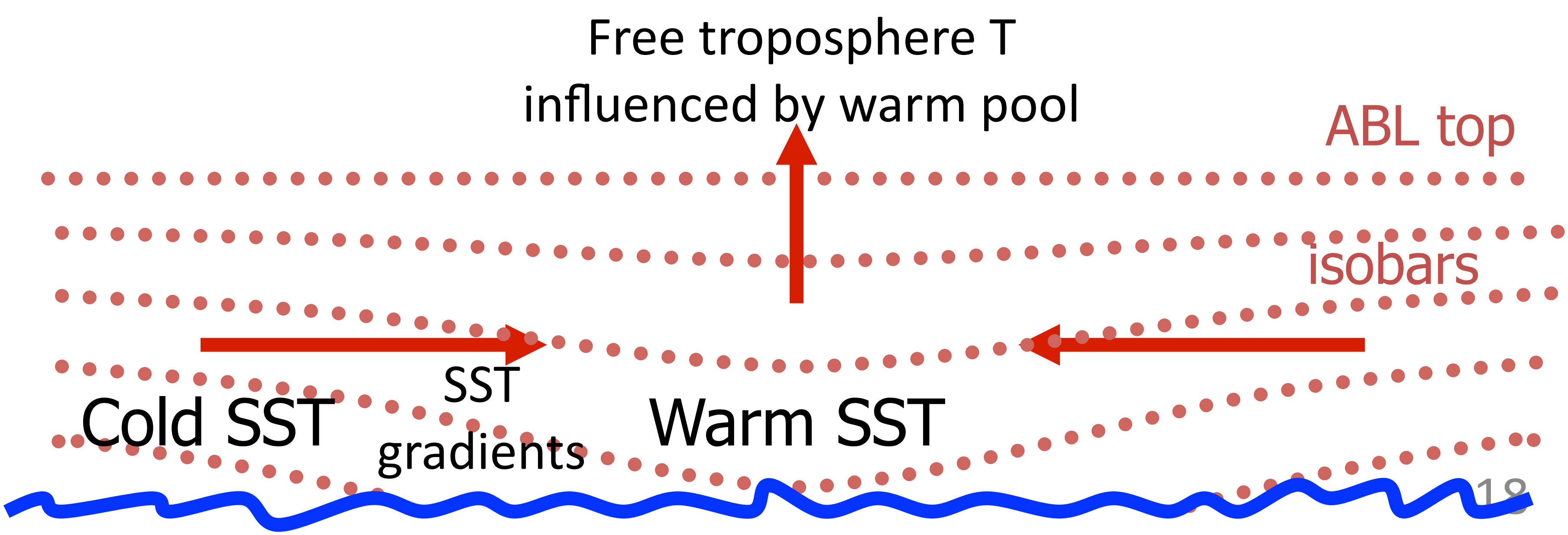
Precipitation and surface fluxes correlated throughout ITCZ



Back and Bretherton, 2005

Why geographic variability in vertical motion profiles, feedbacks?

- Back and Bretherton 2009a showed that Lindzen and Nigam 1987-type mechanism drives most surface convergence patterns,
- Back and Bretherton 2009b showed that depth convection associated w/surface convergenence reaches modulated by local SST
- Deeper convection is associated with greater reductions in radiative cooling when convection happens



Conclusions

- Substantial geographic and temporal variability in vertical motion profiles

- Sometimes convection "self-amplifies" by importing moisture, leading to more convection, when GMS is below threshhold value
    - Threshhold value related to feedbacks between diabatic terms and convection
- Geographic variability in characteristic GMS can be explained by differences in feedbacks