Toward Understanding Differences Between GISS GCM Convective and Stratiform Rainfall and Diabatic Heating and GPM Retrievals

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1. Introduction

Mesoscale organized convection is the dominant source of stratiform rainfall in the tropics, is associated with large cloud shields that impact radiation, and is thought to be associated with diabatic heating profiles whose amplitudes peak above the melting level (i.e., mid-trop. heating associated with convective towers, with stratiform heating above the melting level with cooling below (**bottom left**) that averages to a top-heavy heating profile (**bottom right**)). The vertical profile of diabatic heating is important given the coupled relationship between heating and the general circulation. Thus, it is largely agreed that general circulation models (GCMs) need to represent mesoscale organized convection to ensure the fidelity of their climate change projections (Tobin et al. 2013; Bony et al. 2015).

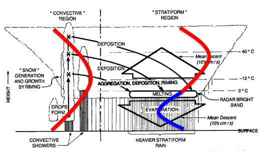
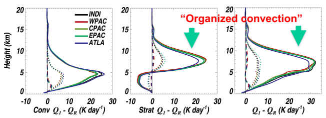


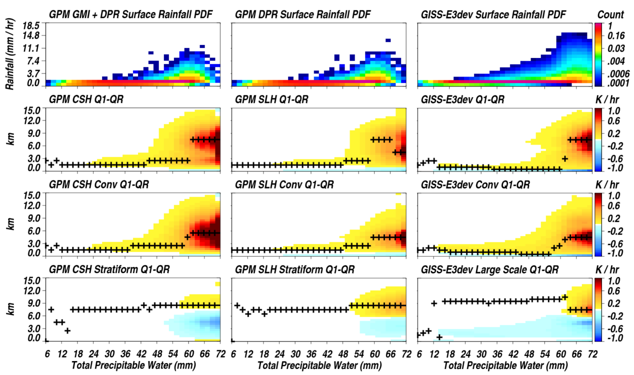
Figure 2. Schematic diagram of the precipitation mechanisms in a tropical cloud system. Solid arrows indicate particle trajectories (adapted from Houze 1989).



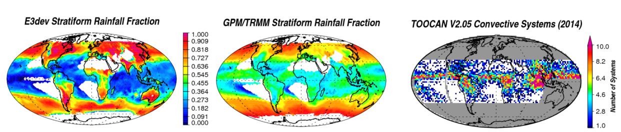
Elsaesser et al. (2010), Figs 5 and 6.

2. Diabatic Heating and Rainfall Climatology

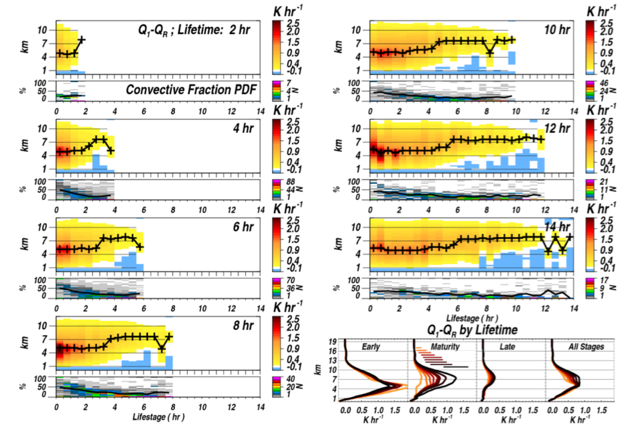
Cold pool parameterization (Del Genio et al. 2015), observations-based (including MC3E and NAMMA) parameterization of convectively-detrained ice (Elsaesser et al. 2017), and MG2 microphysics (Gettelman et al. 2015) [which allows for more realistic evolution of detrained ice] for the first time allows for the in-development GISS GCM to produce a top heavy heating (no radiation, so Q_1-Q_R) profile for water vapor > 60 mm (in closer agreement with GPM CSH & SLH).



Improvement in GCM Q_1-Q_R occurs at the expense of more rain (few 0 mm/hr rainfall rates in **top right** GISS-E3dev panel). Evaluation of GCM rainfall, including both convective & stratiform components, against a combined GPM/TRMM climatology reveals that GCM overproduction of rainfall is largely the result of too much convective rainfall, and not enough stratiform rainfall (**image below**). Overproduction of convection may lead to an overproduction of weak non-MCS anvils (with top-heavy heating) that led to the improvement in Q_1-Q_R (but for a reason different than in nature where MCS-anvils are driving Q_1-Q_R). Indeed, the regions of largest discrepancies are those for which MCSs are the dominant source of rainfall and Q_1-Q_R (**bottom right**, database from Fiolleau and Roca). **To understand differences in rain/heating more completely, we analyze retrievals at the system- (or process-) scale; results then can inform GCM physics.**

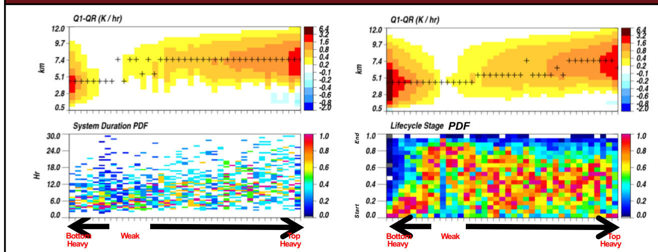


3. Q_1-Q_R and Convective System Duration



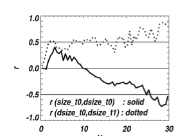
Convective systems are provided by **Fiolleau and Roca** (**TOOCAN database**). Composite Q_1-Q_R and conv. fractions are shown (as a function of stage) for systems whose durations are < 14 hrs. At maturity (definition: temporal midpoint of system), longer-lived systems have more top-heavy Q_1-Q_R (light-dark shading → 2-18 hr. systems in 2 hr increments; horizontal colored lines denote variability at 7 km). Q_1-Q_R at maturity influences the all-stage mean, so that longer-lived systems are more top heavy. Other key points: cooling in lower-trop and transition to top-heavy Q_1-Q_R occurs at maturity. From a GCM perspective, this may suggest a parameterization of org. convection should have a quick transition toward top-heavy Q_1-Q_R at maturity, regardless of how long convection is occurring.

4. Are Q_1-Q_R & Duration Composites Misleading?

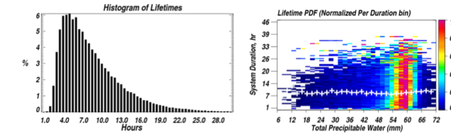


Q_1-Q_R profiles for all systems at the temporal midpoint of their lifetimes were extracted and sorted according to top-heaviness (**top left panel**). Systems are not always top heavy at what was defined as the mature midpoint stage (suggested in **Section 3 composites**). (**btm left panel**) Corresponding PDF of durations; scatterplot suggests that while composites show a clear relationship between top-heaviness and duration, substantial variability is masked. (**right column**) Same sorting performed except for all lifecycle stages (0=system initiation, 1=system termination). Except at initiation, where heating is bottom heavy, no systematic relationship between stage and heating emerges. Overall: top-heavy heating occurs at various lifecycle stages and is only weakly related to duration.

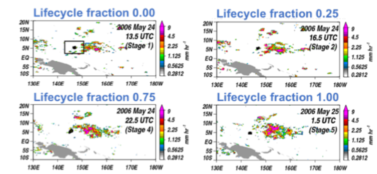
(**Right**) For all systems and hours relative to initiation, the correlation (r) between system sizes and change in size (**solid**) and the change in size at one time (t0) and the change in size at the next time stamp (t1) (**dash**). r is small, suggesting little memory and little prediction of duration. Perhaps the "average" system goes through random changes in organization, with duration & size being an emergent property that results from an accumulated sum of all the random changes in system size that occur as the system traverses an environment whose thermodynamics vary?



5. Conv. System Relationship with Environment



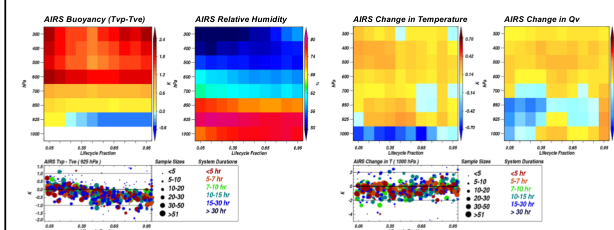
(**Left**) Water vapor does not select short versus long lived systems. But, water vapor does select the absolute number of systems.



~12 hour map of rainfall and one system evolution (in box, moving W). Define lifecycle fraction: 0 = start of tracked system, 1 = end.

Co-locate AIRS orbital level products to systems at each stage.

(**below left panels**) Co-located AIRS buoyancy profiles (computed by raising surface parcel pseudo-adiabatically) and relative humidity as a function of the lifecycle fraction (composite over all systems; fraction = 0.5 at max system size). Systems may decay when they do because of PBL stabilization. Scatterplot of planetary boundary layer (PBL) buoyancy for different durations suggests this result is robust. (**below right panels**) Composite of change in T and Qv as systems move through (after minus before) as a function of lifecycle fraction; PBL cooling is evident (in composites, and in a scatterplot for all systems). The stability of the PBL may drive how systems evolve, and since cooling is transient, PBL stability changes may be driven by mesoscale changes (cold pools? quick SST variations?) instead of large-scale state changes.



6. Physical Interpretation of Results

System duration is strongly tied to maximum size (previous poster / talk results). *Maximum size may be the net result of the competition between convective plume regeneration of stratiform cloud and evaporation of the cloud at system shield edges* (along with supplemental stratiform sustenance driven by mesoscale ascent tied to depositional heating in a supersaturated environment that occurs in association with <0.25K T changes).

If convective plume regeneration is cut off due to a stabilizing PBL, the net effect could be system shield decay (at a rate that depends on environmental humidity and the mesoscale ascent affect). When the last vestiges of the cloud disappears, the duration is "defined."

Under this competition argument, variations in size and Q_1-Q_R along the system track are expected and consistent with these and past results showing substantial variability in systems as they progress (since regeneration or decay of plumes can happen randomly based on whatever is driving mesoscale variations in PBL buoyancy). In this sense, for systems passively following the mid-tropospheric steering flow (not shown here, but our recent results suggest this is the case for most systems), size (and equivalently, duration) along the Q_1-Q_R composite lifecycle may be an emergent property that happens from the accumulated sum of random growths / decays that dictate the first and last appearance of cloud.