Recent NASA GISS GCM Convective Parameterization Developments Guided by GPM Satellite Retrievals

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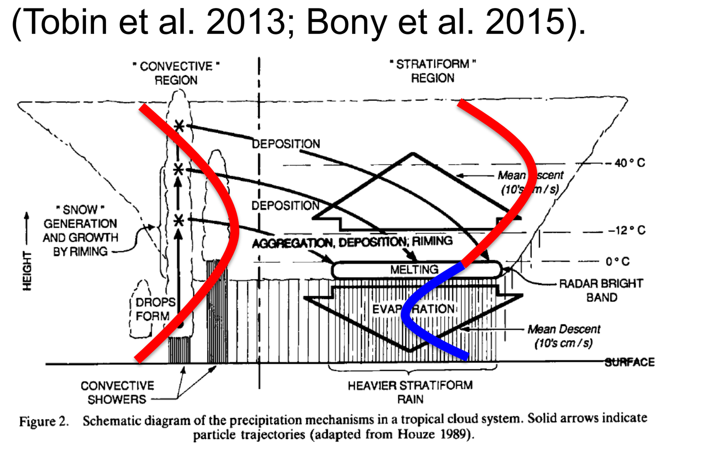
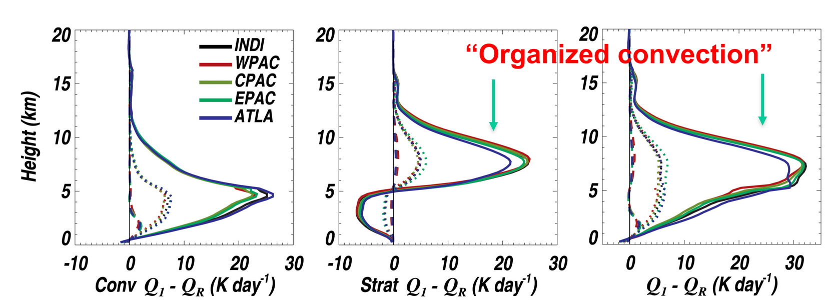
1. Introduction

There is an ongoing effort to add physics into the NASA GISS general circulation model (GCM) convective parameterization that facilitates simulation of organized convection. Organized mesoscale convective systems (MCSs) are the dominant source of tropical rainfall, comprise large cloud shields that impact radiation, and are associated with diabatic heating profiles (that are tightly coupled to the large scale circulation) 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**)). For these reasons, **it is largely agreed that GCMs need to represent mesoscale organized convection to ensure the fidelity of their climate change projections** (Tobin et al. 2013; Bony et al. 2015).

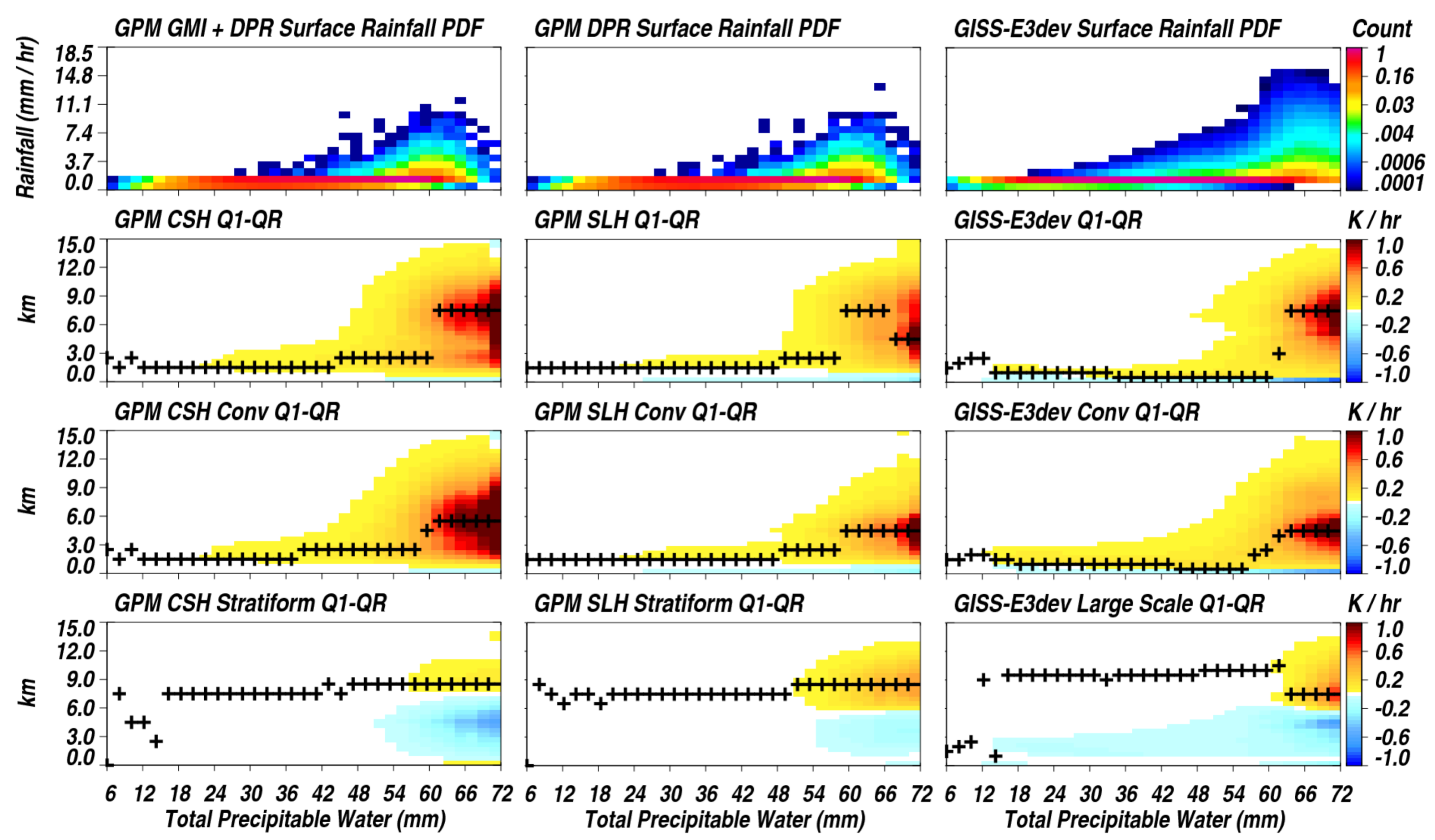




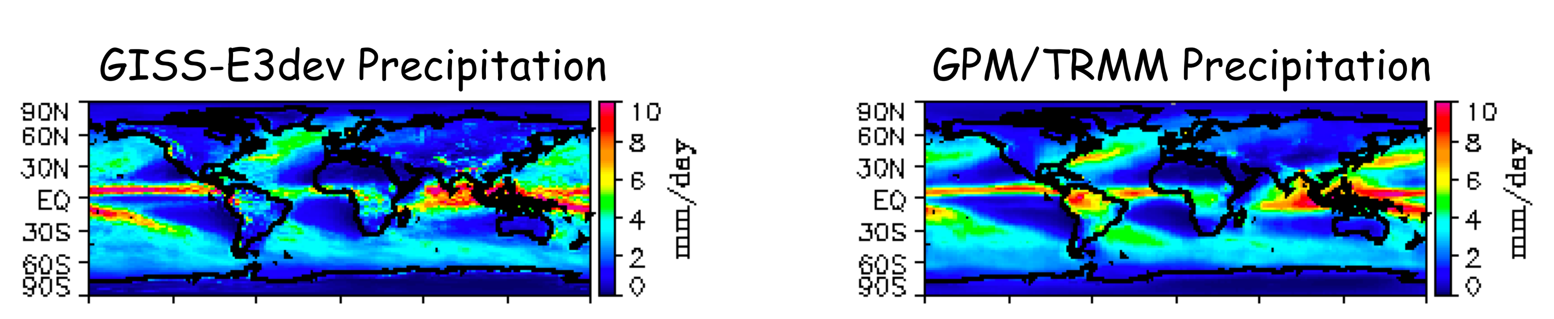
Elsaesser et al. (2010), Figs 5 and 6.

2. Diabatic Heating and Rainfall Climatology

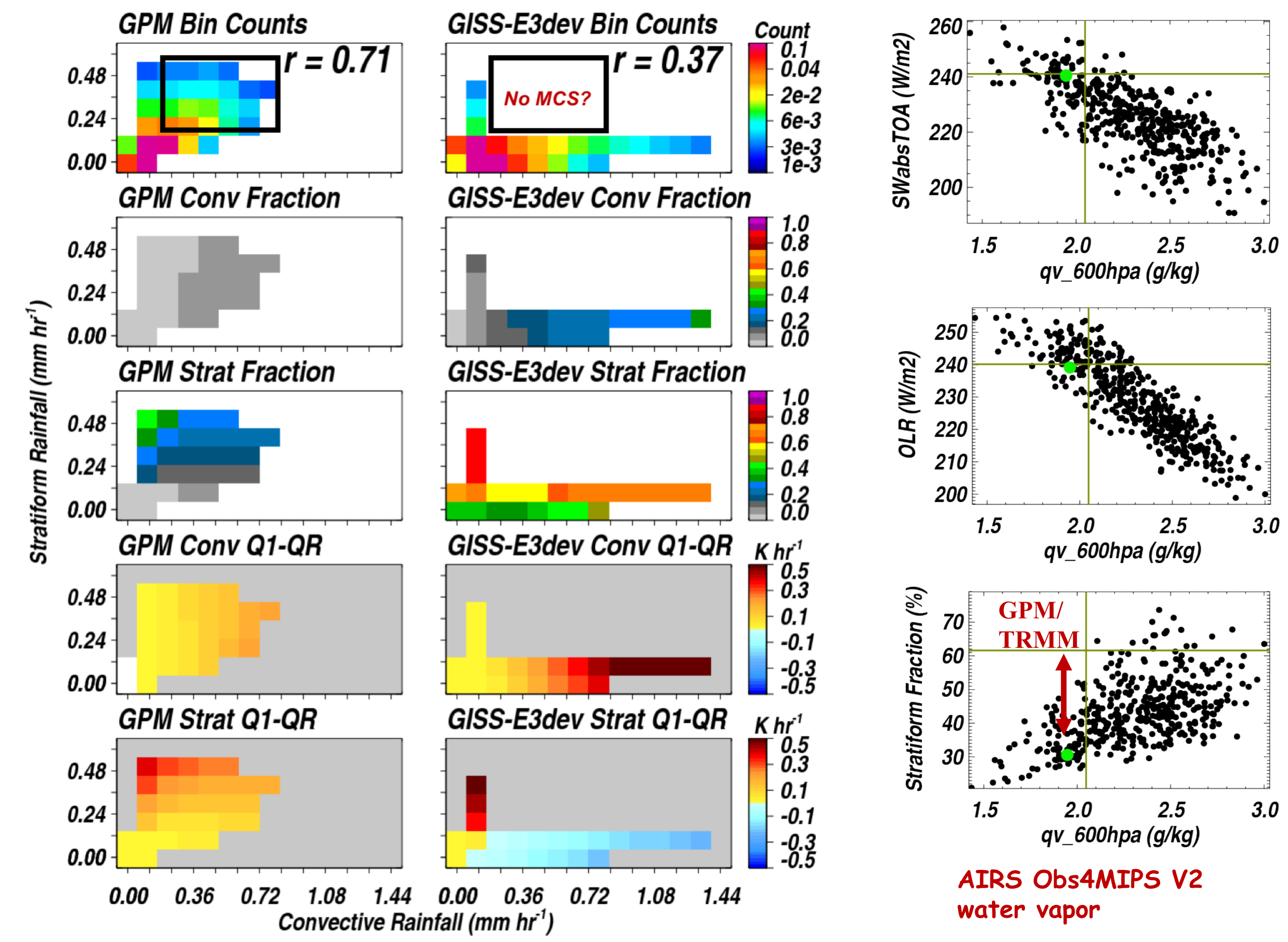
New physics expected to facilitate convective organization include: cold pool parameterization (Del Genio et al. 2015), observations-based (including MC3E and NAMMA) parameterization of convectively-detrained ice (Elsaesser et al. 2017), and MG2 microphysics (Gettelman et al. 2015) [facilitates more realistic evolution of detrained deep-convective ice]. **With these new developments, the GISS GCM, for the first time, is able to simulate a top heavy heating** (no radiation, i.e., Q_1-Q_R) **profile** for water vapor > 60 mm (**in closer agreement with GPM CSH & SLH**).



Coincident with improvement in diabatic heating, regional biases in rainfall (**image below**, evaluated against a combined GPM/TRMM climatology) and radiation are smaller. However, rainfall discrepancies remain across portions of the ITCZ, WPAC and over tropical continents (e.g., Amazon basin) where organized convective systems are more commonly found. **To understand differences in rain/heating more completely, we analyze retrievals at the system/process scale (or sub GCM-gridbox scale); results will then be used to further inform GCM parameterization development.**

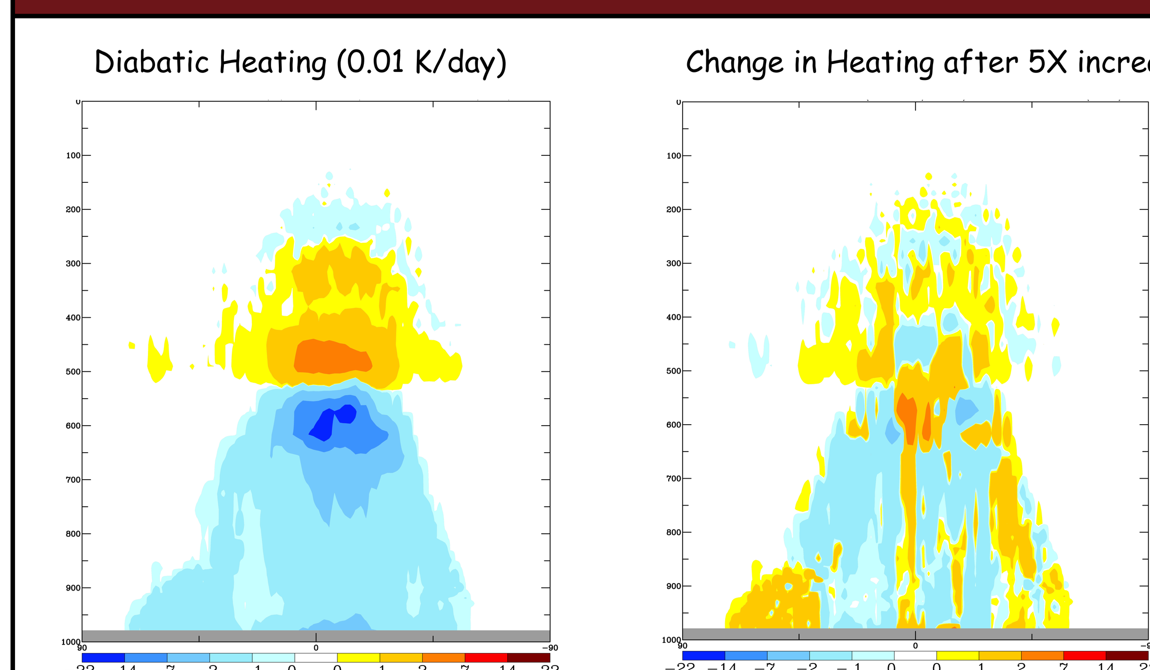


3. New Metrics to Inform Conv. Parameterization



For 2.0° grid boxes (30S-30N), as a function of gridbox average convective rainfall (x-axis) and gridbox average stratiform rainfall (y-axis): the average convective fraction, stratiform fraction, convective heating above the melting level (ML), and stratiform heating above the ML are shown (**left two columns**). **The GCM shows a lack of activity in convection modes characterized by simultaneously-increased convective and stratiform rainfall**; the **Fiolleau and Roca** MCS database (**TOOCAN**) indicates that these regimes are associated with large convective systems. In order for the GCM to simulate reasonable water vapor and radiation (**right column, top two panels; green dot denotes GCM near observed crosshairs**), other convective modes are distorted to account for deficient organized convection physics (here, the GCM increases convective activity in the low conv RR, high strat RR regime, -or- high conv RR, low strat RR regime, in contrast to GPM). A perturbed parameter ensemble (PPE) experiment was conducted to determine if any convective parameterization parameter combination can improve the simulation at high conv./strat. rainfall rates (black dots, bottom right panel above). **No matter the combination, the GCM exhibits this deficiency (e.g. the stratiform fraction climatology, bottom right panel to top, never agrees with the GPM/TRMM climatology except when water vapor is unrealistically high). This result suggests the need for structural improvement in the convective parameterization.**

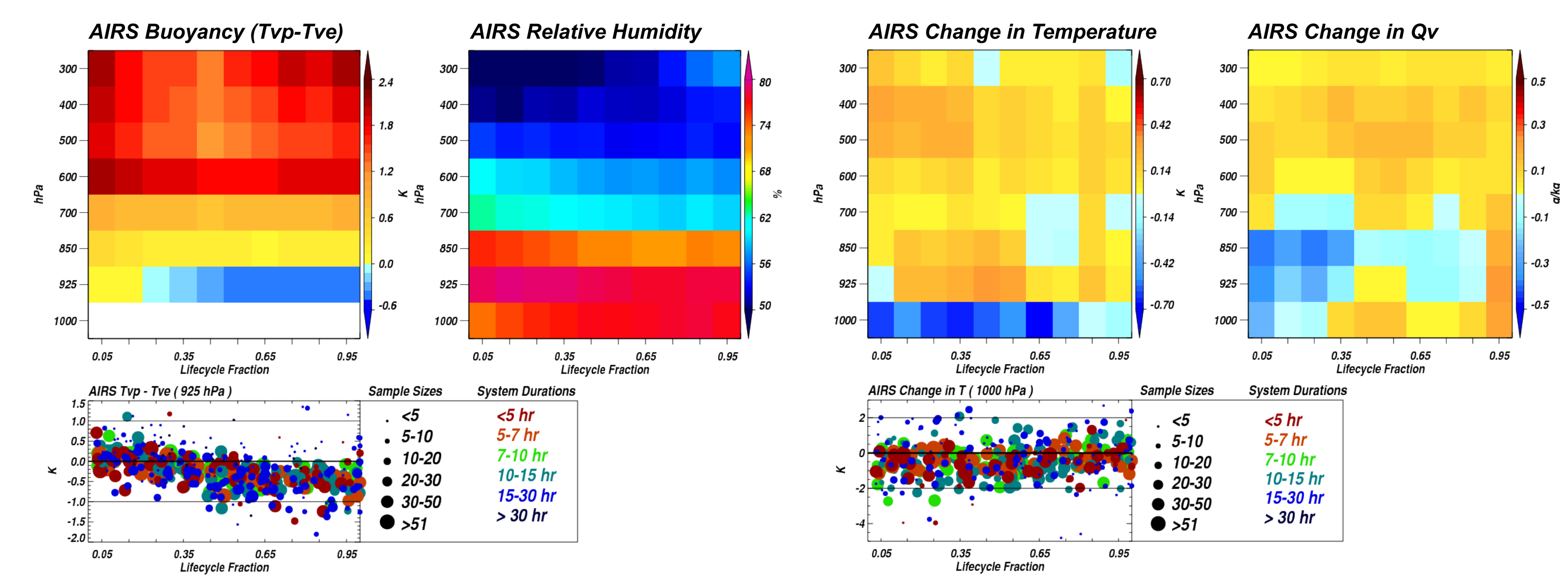
4. Recent Work on Mesoscale Convective Physics



Figures from M.-S. Yao. GCM mesoscale convection diabatic heating profiles as a function of latitude (**left panel**). Change in heating after assuming a 5X increase in the mesoscale region (**right panel**). Profiles exhibit realistic vertical structure, but with weak amplitude (**compare equatorial profiles to Section 2 GPM stratiform Q1-QR**).

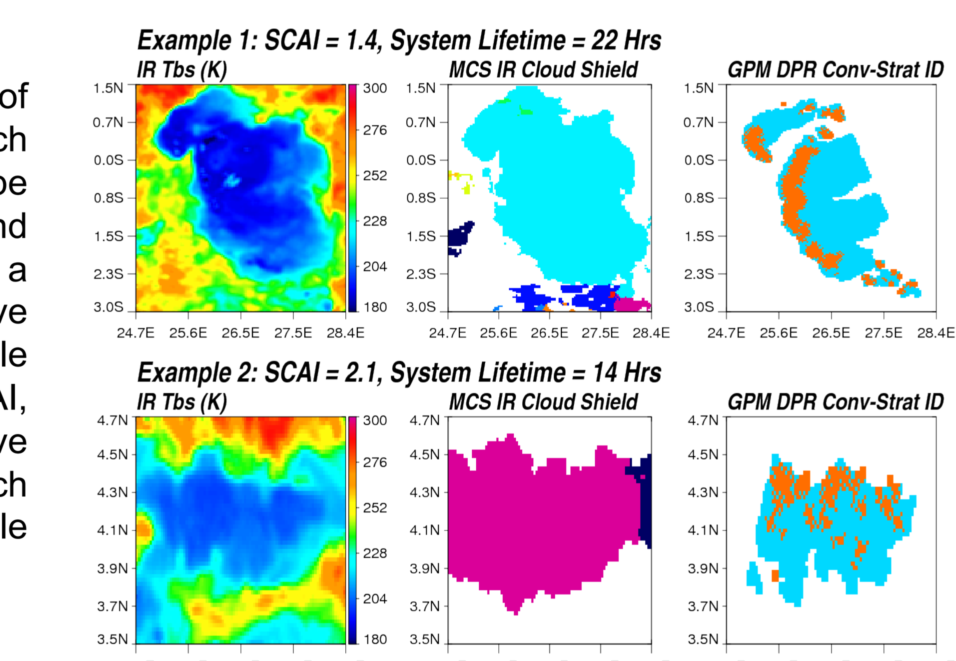
Recent parameterization development includes a focus on the mesoscale cloud associated with organized convection; one approach assumes a balance between latent heating, adiabatic cooling, and radiative cooling. **Key assumptions: How large the mesoscale cloud area is, and how long it lasts. GPM retrievals co-located to the TOOCAN MCS database will inform this component (Section 5).**

5. Convective System Size and Duration



(**Top left two panels**) Co-located AIRS buoyancy profiles (computed by raising surface parcel pseudo-adiabatically) and relative humidity as a function of the convective system 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. (**Top right two 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. **Hypothesis: Mesoscale region size (and thus duration, as these two are strongly related) increases as long as unstable PBL air is re-ingested into convective plumes.**

(**Right panels**) The arrangement of convective/stratiform regions, which may relate to shear, may also be important for understanding size and system longevity. For example, if a system has aggregated convective towers (top row, with a lower simple convective aggregation index [SCAI, Tobin et al. 2012]), convective duration may be increased. Such knowledge will inform the mesoscale convection parameterization (Section 4).



6. Conclusions and Future Plans

New GISS-GCM physics has led to an improved climatology of diabatic heating and rainfall. An evaluation of stratiform and convective rainfall and diabatic heating at the GCM gridbox-scale suggests that further structural improvement in convective organization physics is needed.

Conceptualization of new physics will continually be guided by GPM pixel-level retrievals of rainfall, diabatic heating, and convective/stratiform information. System duration is strongly tied to maximum size (previous poster / talk results). We hypothesize that *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).

The conceptual framework for understanding size and duration will inform the development of our mesoscale convective parameterization (which currently largely depends on gridbox radiative cooling profiles), with size perhaps being tied to convective plume heating, and duration perhaps being tied to the extent to which undisturbed buoyant PBL air (outside of the GCM cold pool) is re-ingested into the convective plume.