Mesoscale Convective System Cloud Shield Expansion Rates and Connection to Convective Latent Heating

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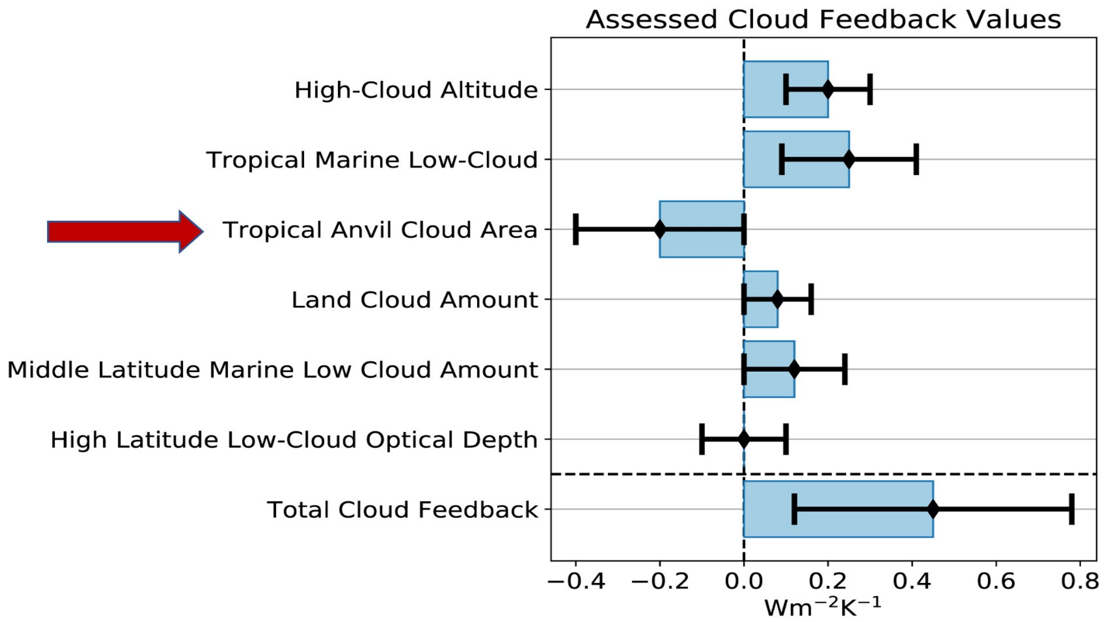
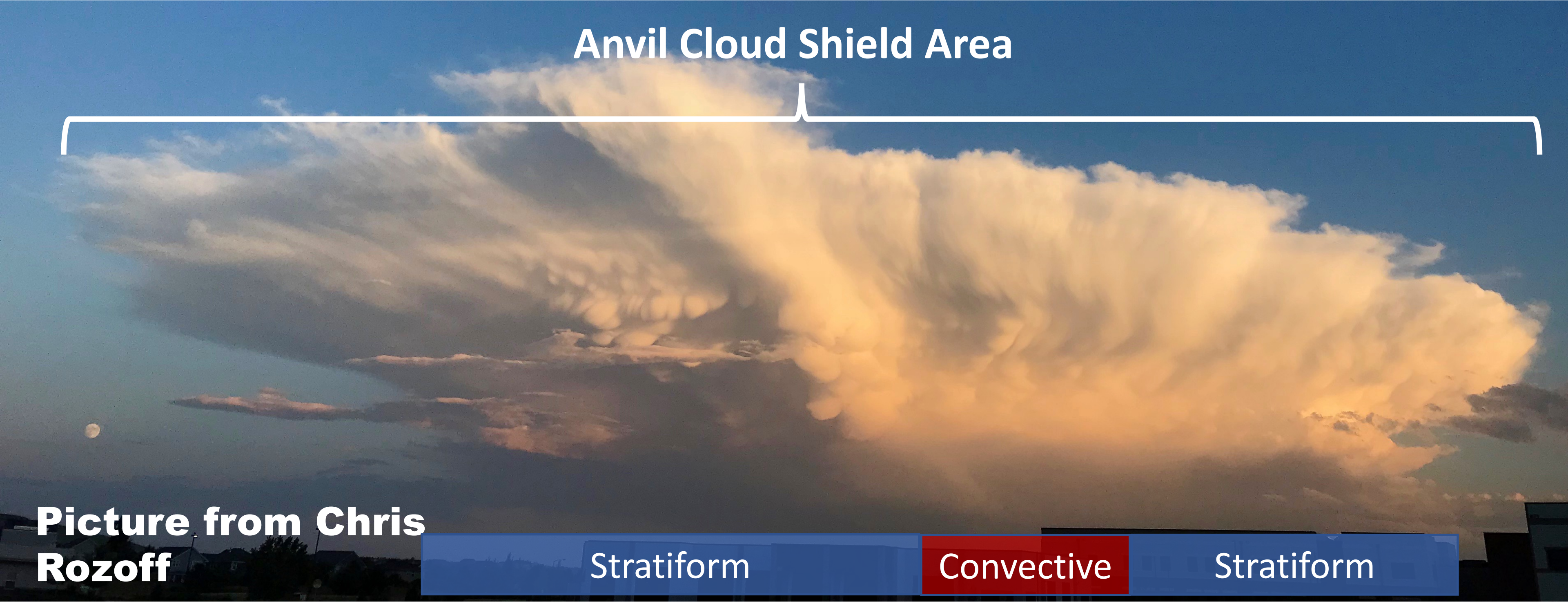
Why do we care about system sizes and overall cloud shield area?

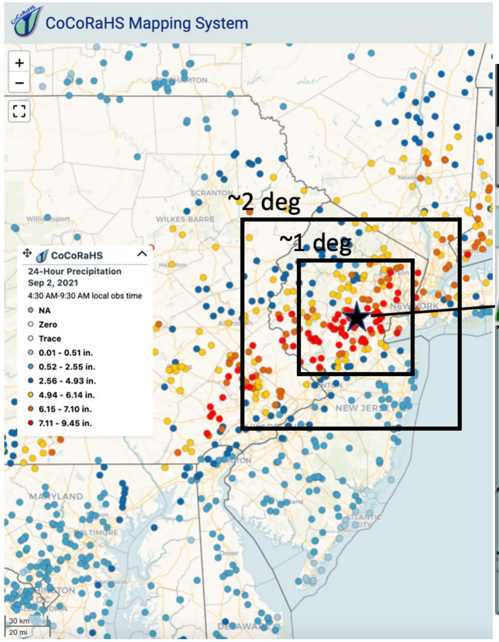
Sherwood et al. (2020, Rev. Geophys.)

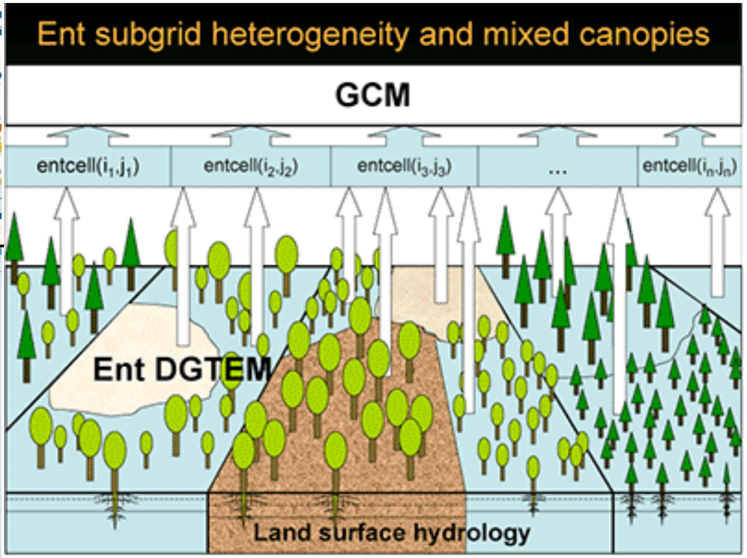


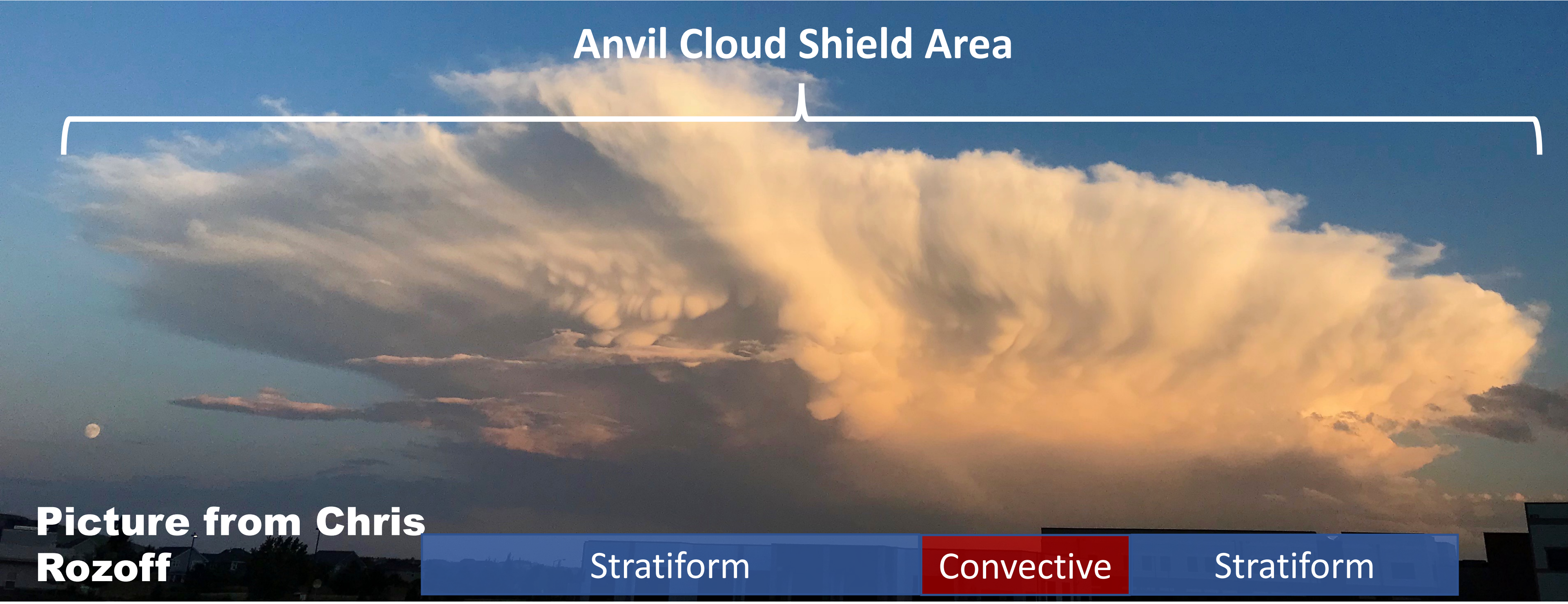


Why do we care about system sizes and overall cloud shield area?

Limitations to using GCM grid-box average instantaneous rainfall rates for assessing extremes, flood potential, surface hydrology, etc.

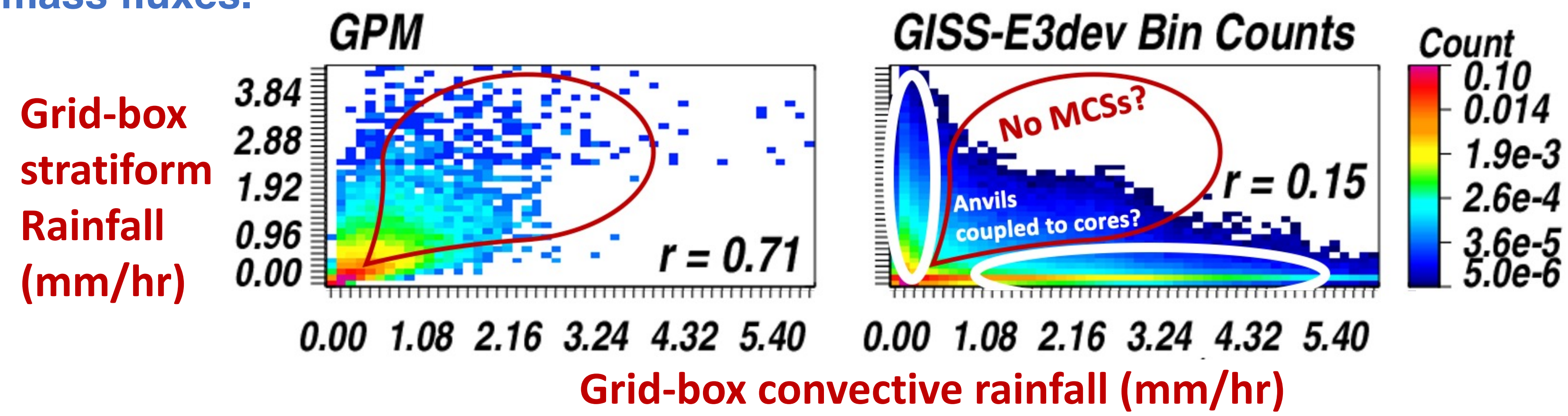




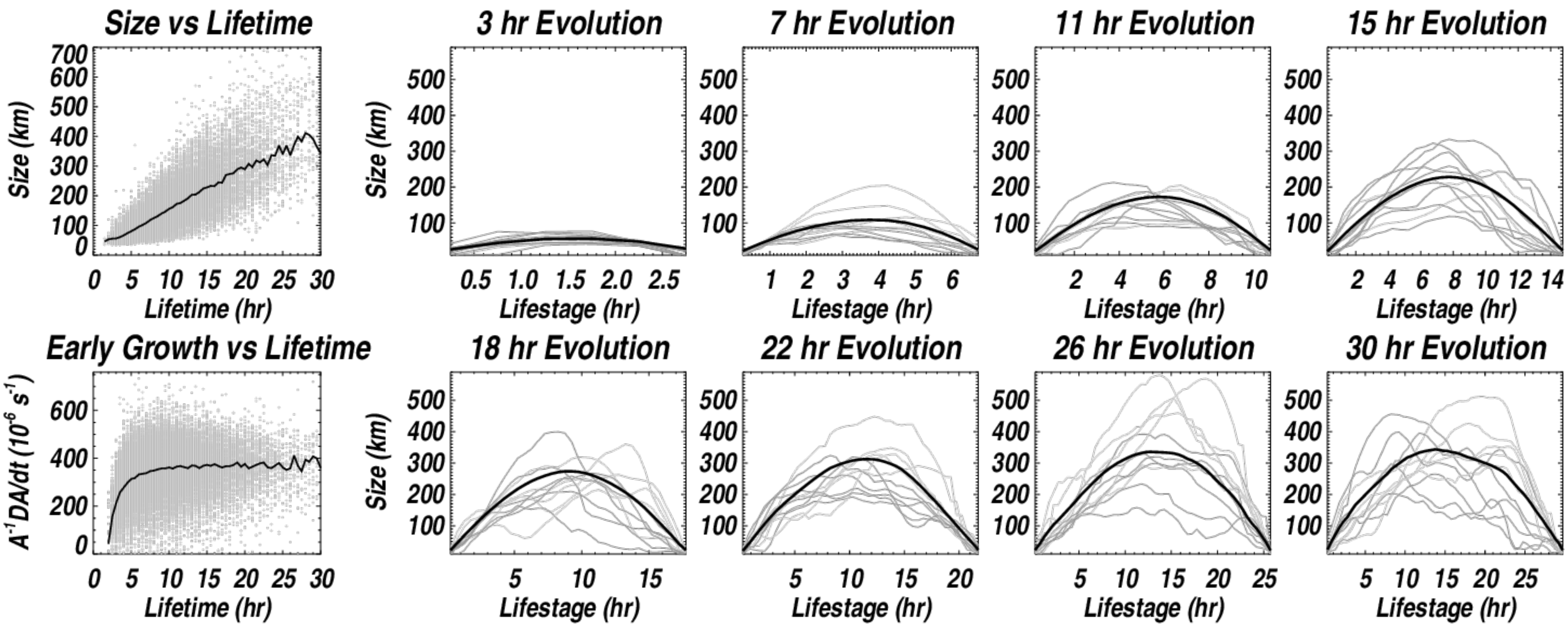


In parameterized GCMs?

Convection-driven stratiform & anvil areas often know nothing about convective mass fluxes.



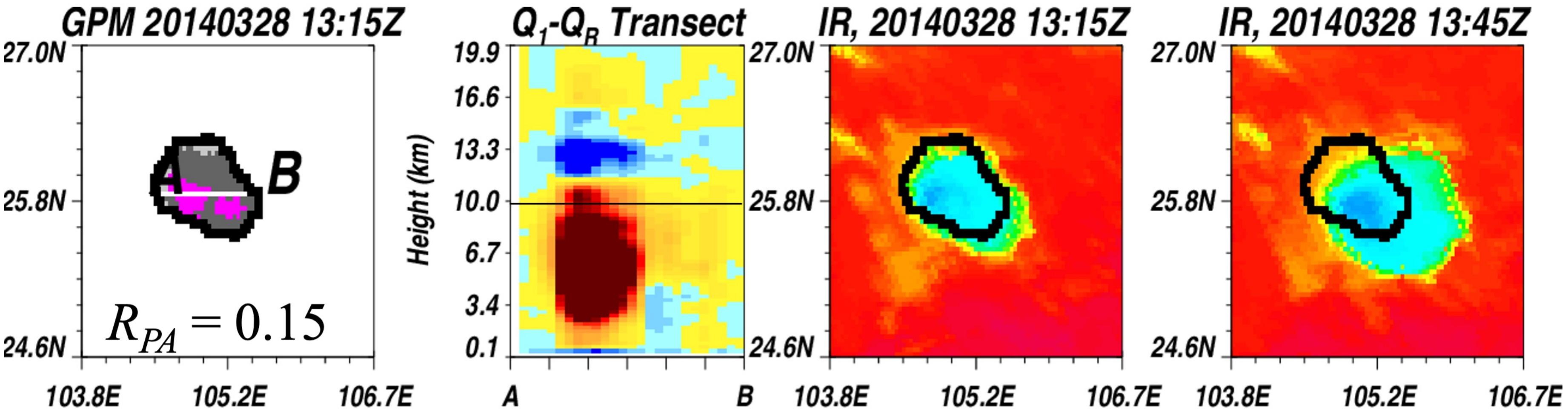
At the convective system scale, it is known that long-lived systems have larger cloud shields, on average…



…but, composites size evolutions hide a typically messy evolution toward variable maximum sizes.

Simple Model of Convective System Area Growth Rates:

1. Terms informed by orbital level satellite data mapped to systems.
2. Connect tracked anvil cloud shields areas to convective mass flux, as in nature.
3. Easily implementable as an anvil cloud area parameterization?



Area (A) Time Change ~ Conv. Cell Production **+ mass flux terms –** rainout/mixing

$$\frac{dA}{dt} \approx A_{c,\mathrm{SRC}} - \frac{1}{\rho}\frac{dM_c}{dz} - \frac{1}{\rho}\frac{dM_s}{dz} - \frac{A}{\tau}$$

Elsaesser, G. S., et al., 2022: A simple model for tropical convective cloud shield area growth and decay rates informed by geostationary IR, GPM, and Aqua/AIRS satellite data. *JGR:A*, 127, e2021JD035599. https://doi.org/10.1029/2021JD035599

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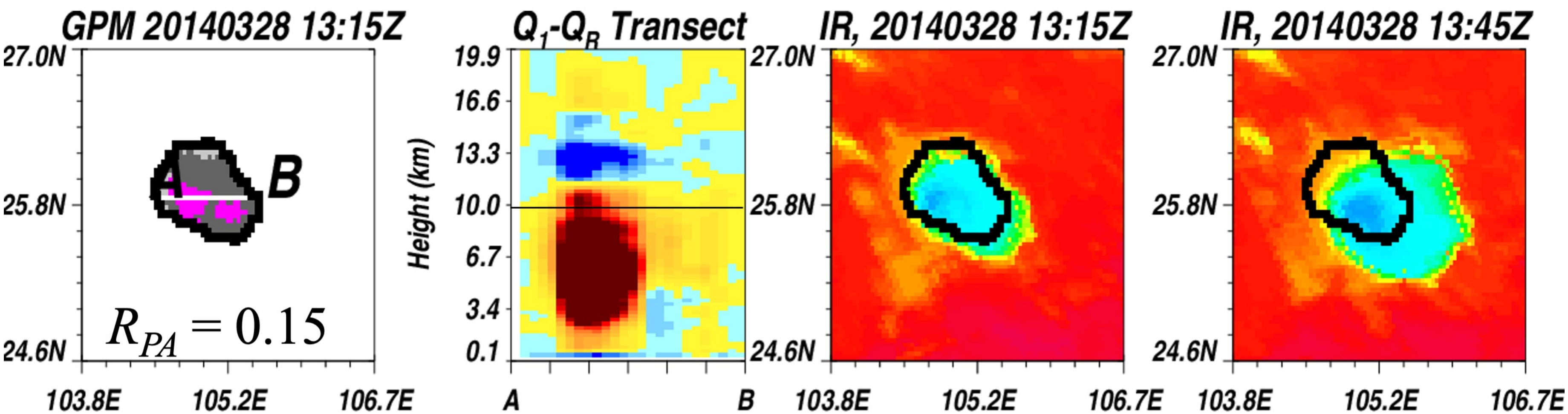

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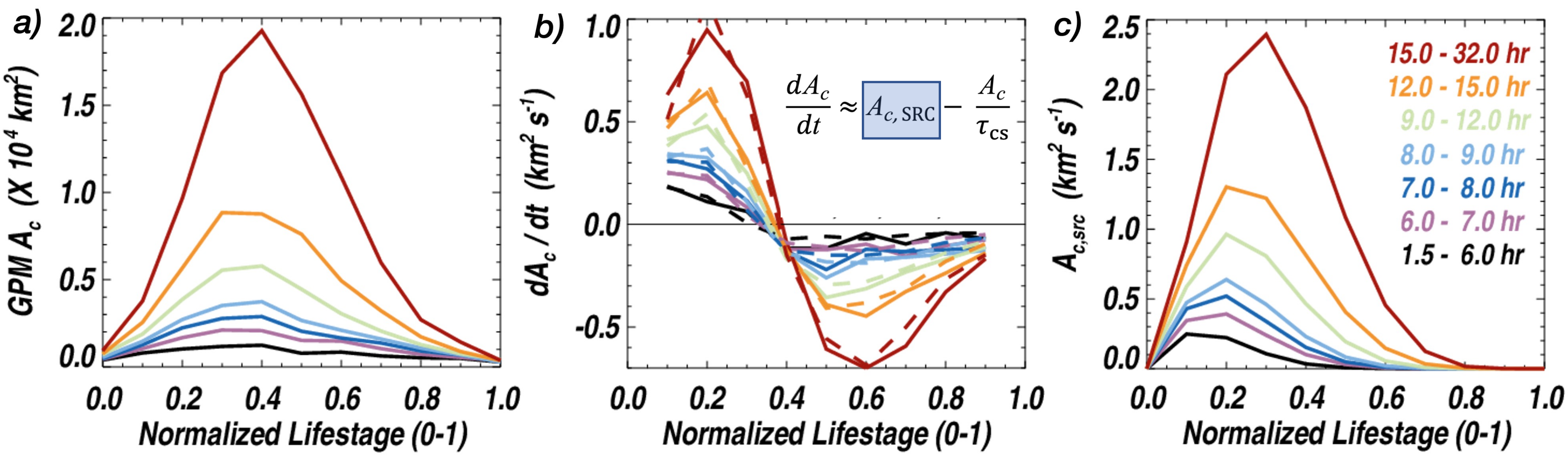
Constrain $A_{c,\mathrm{SRC}}$ with GPM satellite data

$A_{c,\mathrm{SRC}}$ is likely very connected to local environments, cold pools.



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X

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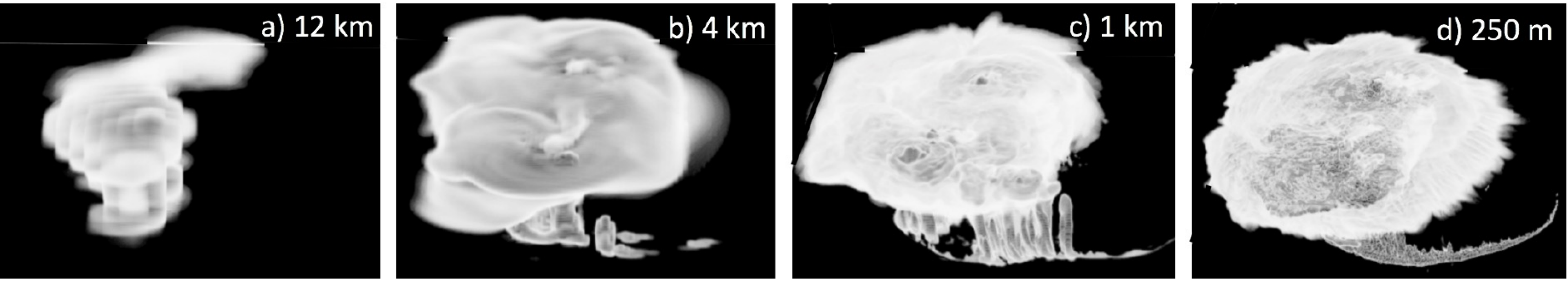
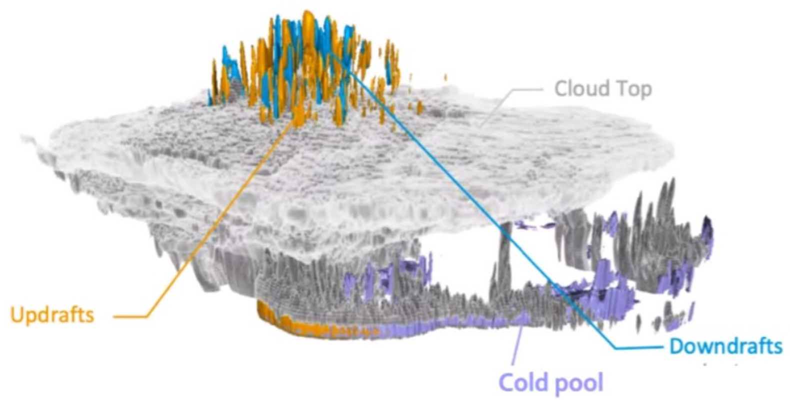
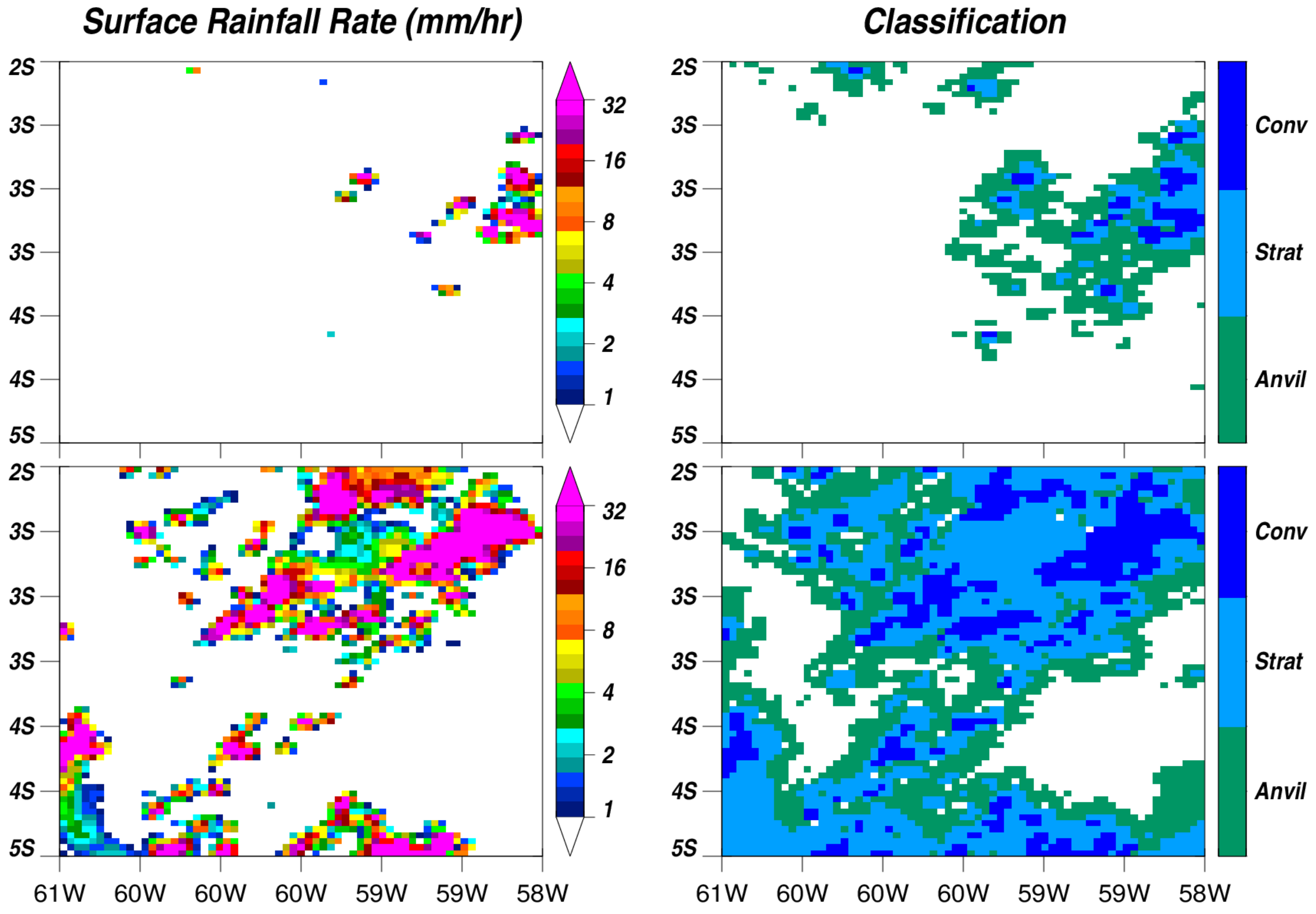
Convective mass flux is not observed over the global tropics (yet!)
Can we use satellite diabatic heating and T/qv structure to estimate?

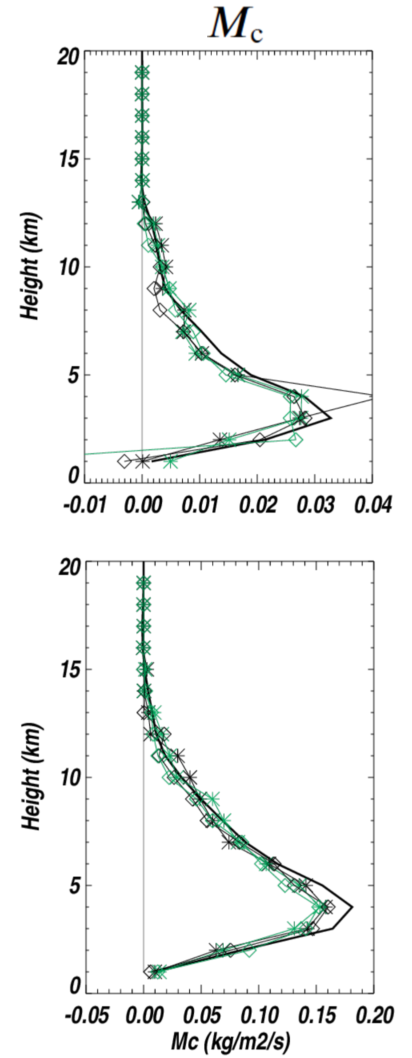




MCS Simulations provided by Andreas Prein (NCAR)

WRF Convective Mass Flux vs Estimate from Q_1 and T structure.



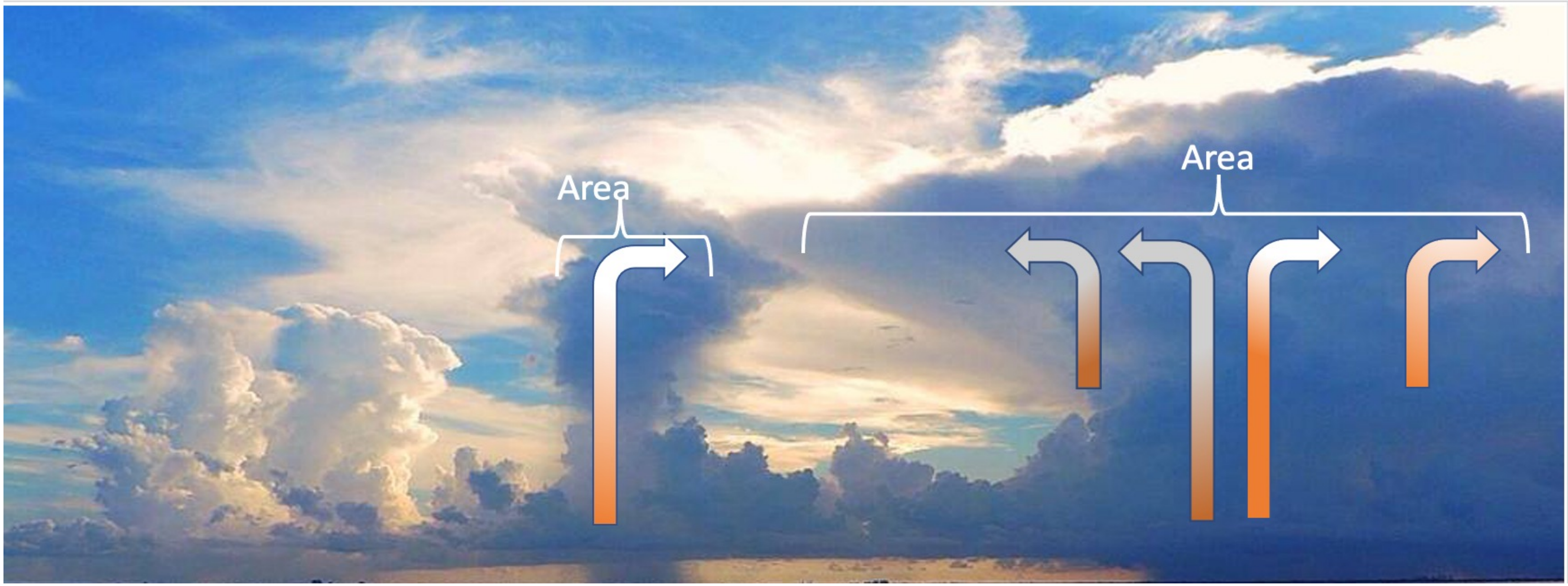


WRF heating (**Q1=LH+QR+eddy,** averaged across convective cores) is very related to M_c at all levels. Dominant term? : **Latent Heating (LH)**

$$M_c \approx \rho A_c \left(\frac{1}{c_p} \frac{ds}{dz} \right)^{-1} (LH_{\mathrm{Conv}})$$

Solid: WRF;
Lines with symbols: ds/dz from different environments

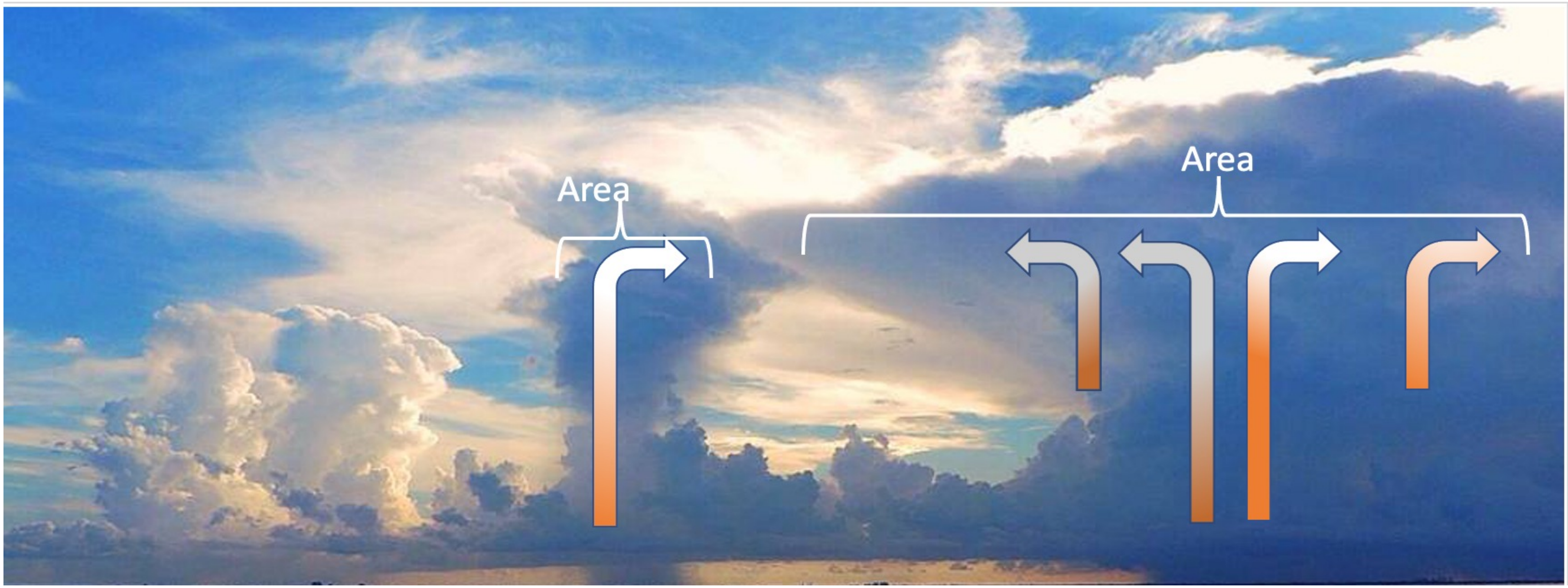
Simple Model of Convective System Area Growth Rates



Area (A) Time Change ~ New conv. area + strat. area production − rainout/mixing

$$\frac{dA}{dt} \approx A_{c,\,\mathrm{SRC}} \;-\; \frac{A_c}{\rho}\frac{d}{dz}\left(\rho\,\frac{Q_1\text{-}Q_{R_{\mathrm{Conv}}}}{\Gamma - \Gamma_d}\right) \;-\; \frac{A}{\tau}$$

Simple Model of Convective System Area Growth Rates



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GEO-IR (TOOCAN MCSs)

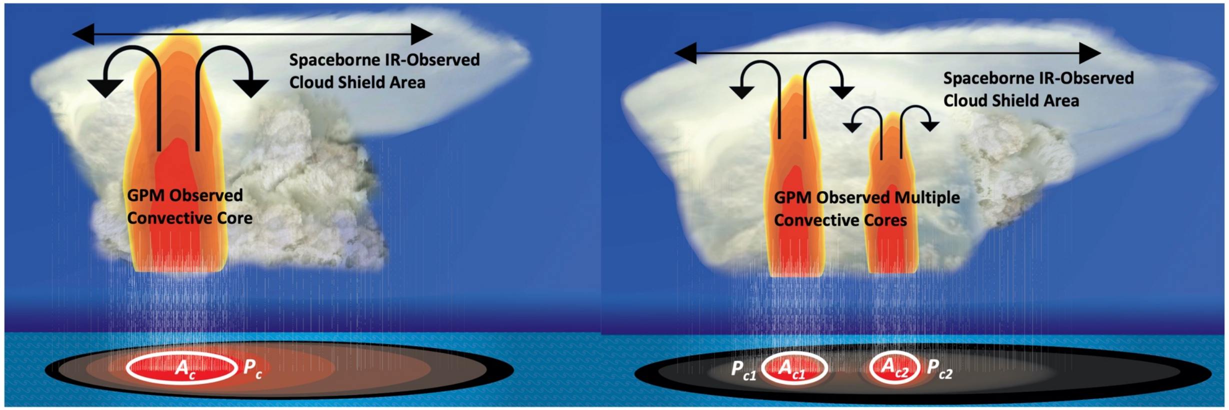
$$\frac{dA}{dt} \approx A_{c,\,\mathrm{SRC}} - \frac{A_c}{\rho}\frac{d}{dz}\left(\rho\,\frac{Q_1\text{-}Q_{R_{\mathrm{Conv}}}}{\Gamma - \Gamma_d}\right) - \frac{A}{\tau}$$

GPM

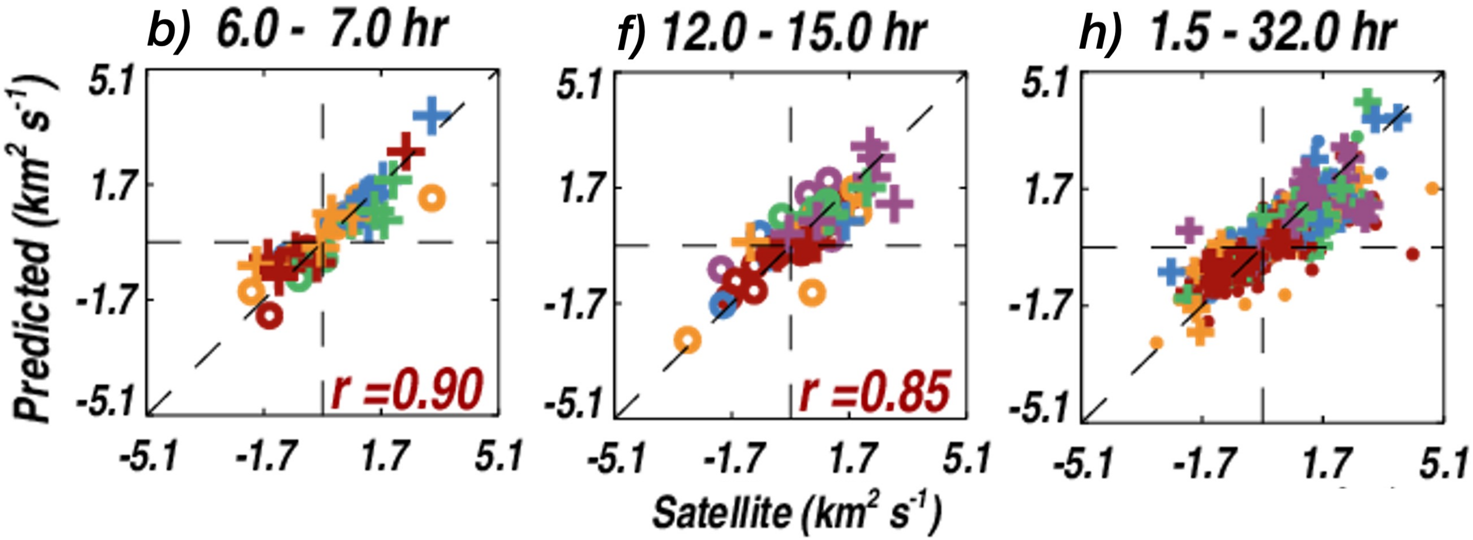
AIRS/sounder data

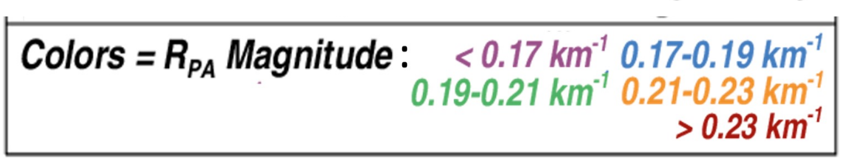
Solve for tau, system-type independent.

Model does well in different convective aggregation states, over land vs ocean, and for different convective system life stages.



Less aggregation, Larger R_{PA} (i.e., ratio of convective core perimeters to total convective area)





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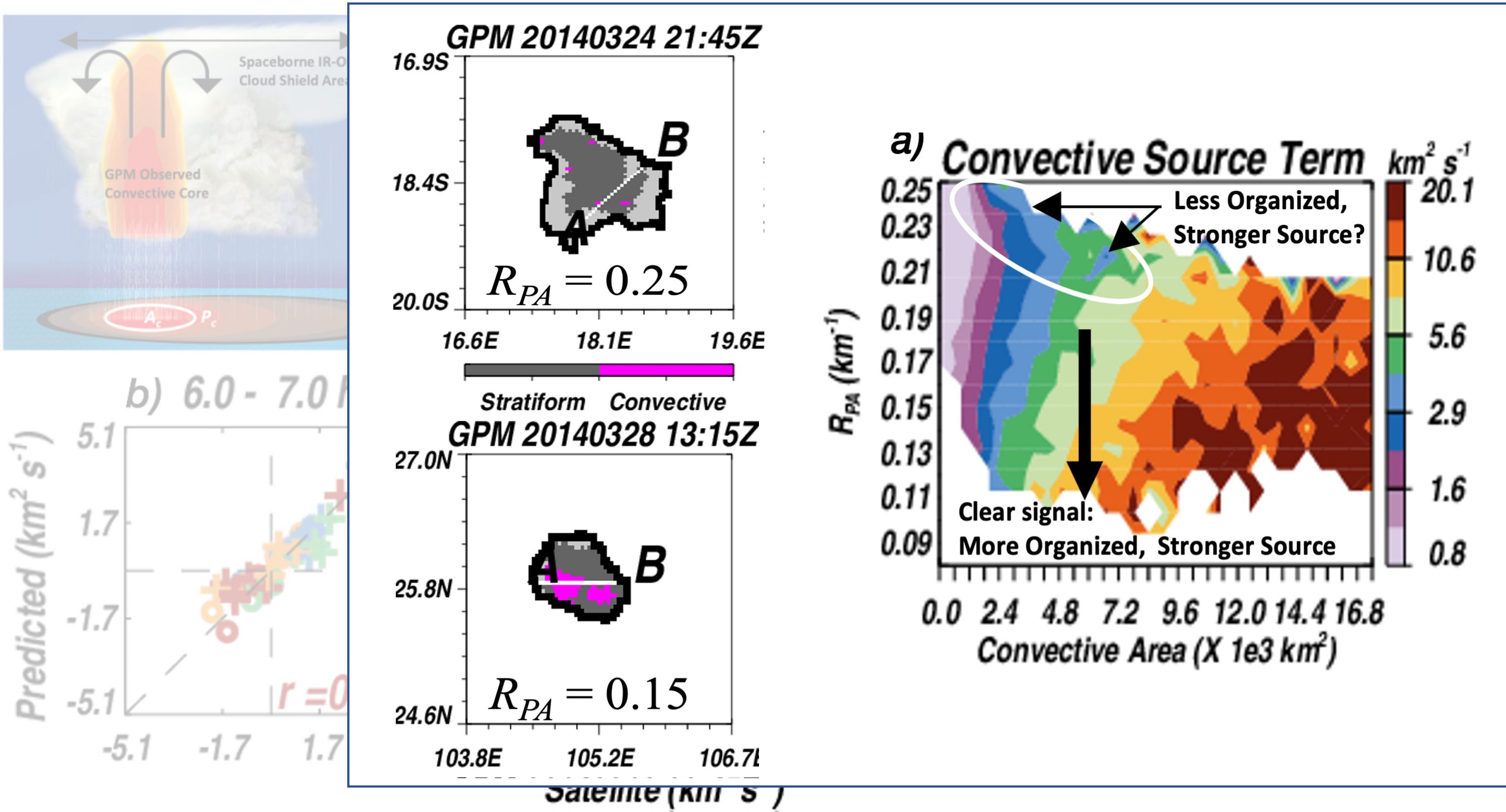
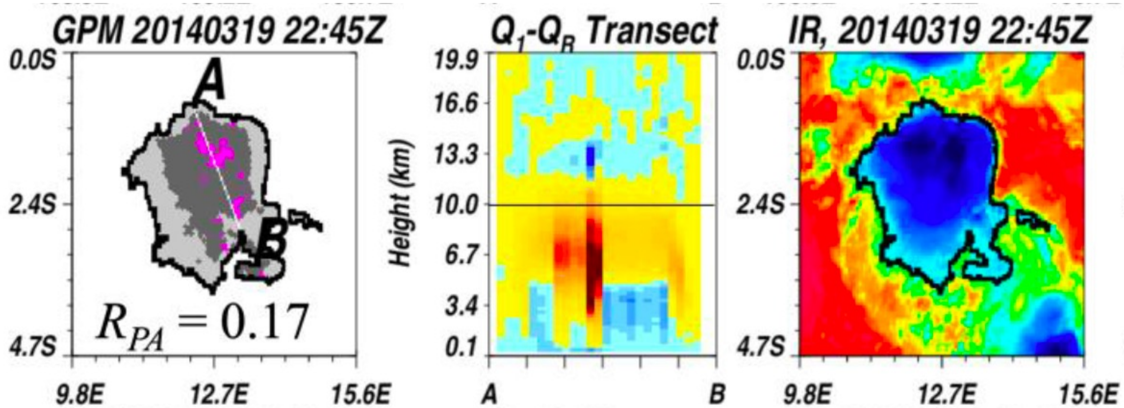
Model does well in different convective aggregation states, over land vs ocean, and for different convective system life stages.



Colors = R_{PA} Magnitude : < 0.17 km^{-1} 0.17-0.19 km^{-1} 0.19-0.21 km^{-1} 0.21-0.23 km^{-1} > 0.23 km^{-1}

$$\frac{dA}{dt} \approx A_{c,\mathrm{SRC}} - \frac{A_c}{\rho}\frac{d}{dz}\left(\rho \frac{Q_1 - Q_{R_{\mathrm{Conv}}}}{\Gamma - \Gamma_d}\right) - \frac{A}{\tau}$$

How much convection do you need in any system to get growth of the anvil cloud shield?



>>If convection occupies more than **~15%** of the anvil cloud shield, it will grow. **But**, this depends on T lapse rates – if these change with time in the upper troposphere, so too would this threshold.

$$\frac{A_c}{A} \geq C_2 / \left(\frac{1|}{\tau_{cs}} + \ max \left[-\frac{1}{\rho} \frac{\Delta}{\Delta z} \left(\rho \frac{Q_1 \text{-} Q_{R_{\text{Conv}}}}{\Gamma - \Gamma_d} \right) \right] \right)$$

Overall, there doesn't have to be that much convection for growth of a cloud shield.

Conclusions and Upcoming Work

Overarching goal: Improve understanding of how deep convective system anvil cloud shields change ***given the current state of convective cores***.

Can re-arrange *dA/dt* equation, solve for *dAs/dt* (where *As* is stratiform area) and work on implementing into a coarse-resolution GCM.
*At present, GCM deep convection stratiform areas are typically independent of what is going on in the convective towers themselves.

To do: understand better how stratiform rainfall, convective aggregation, and shear fits in toward understanding discrepancies in the model prediction, and work on integrating model to understand distributions of system durations.

Reference:

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