Constraining an Anvil Area Growth Rate Model Using WRF Simulations, DOE/ARM Observations, and Multi -Sensor Satellite Datasets

Greg Elsaesser (NASA GISS/Columbia U)

Jingbo Wu (GISS/CU), Scott Giangrande (BNL)
Andreas Prein (NCAR), Ming Ge (NCAR), Alexandra Ramos (NCAR),
Steve Lang (GSFC), Adrian Loftus (GSFC), Qilong Min (SUNY/Albany)

Acknowledgements: DOE/ASR Grant No. DE-SC0020192, Southeast U.S. AMF3 Site Science Team Funding

Columbia University in the City of New York

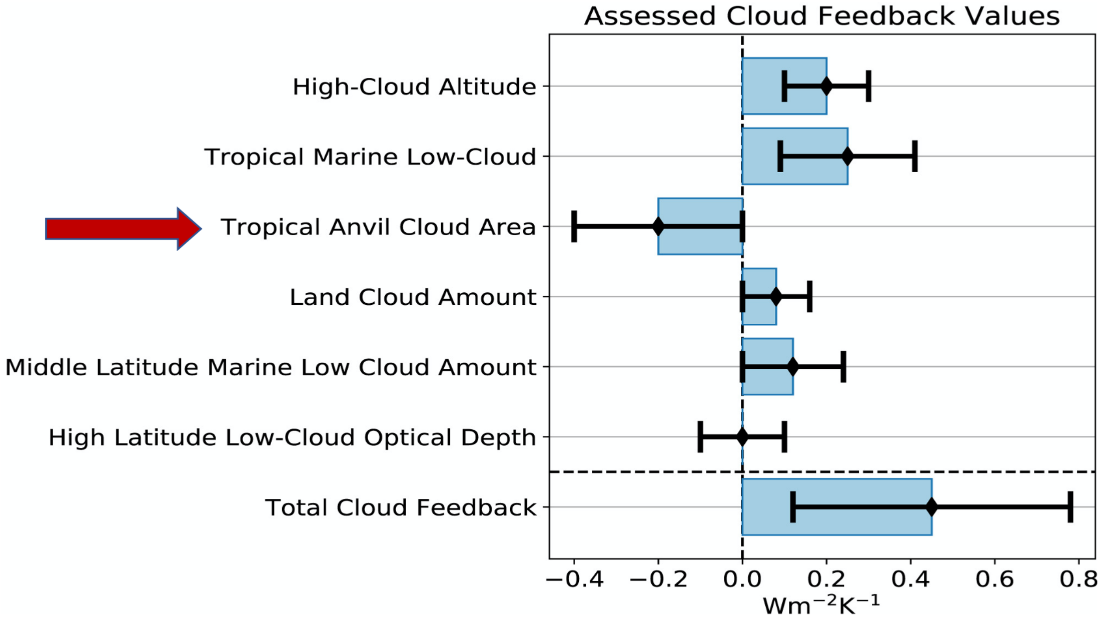
Elsaesser, Wu, Giangrande, Prein et al.
2022 DOE ARM/ASR PI Mtg
Convective Proc. WG Plenary Talk

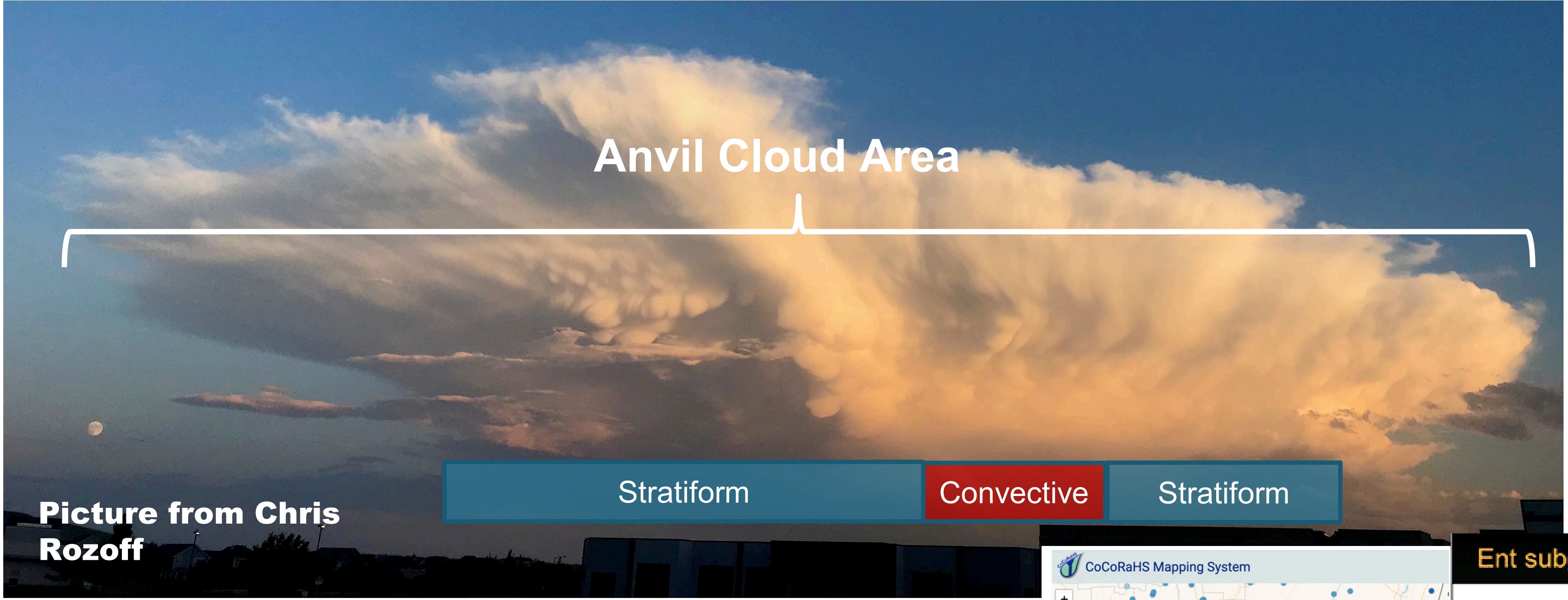
ASR Atmospheric System Research

U.S. Department of Energy | Office of Science

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

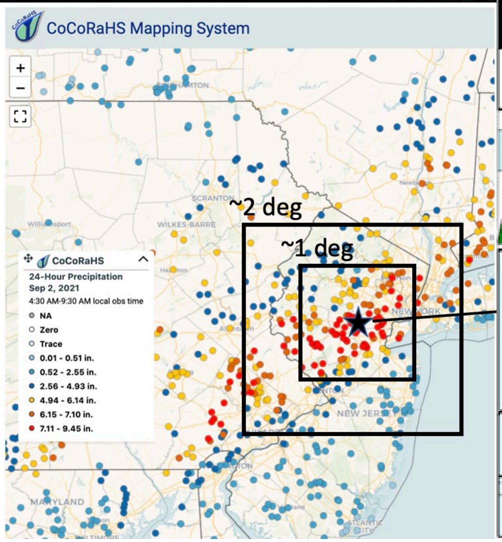
Sherwood et al. (2020, Rev. Geophys.)

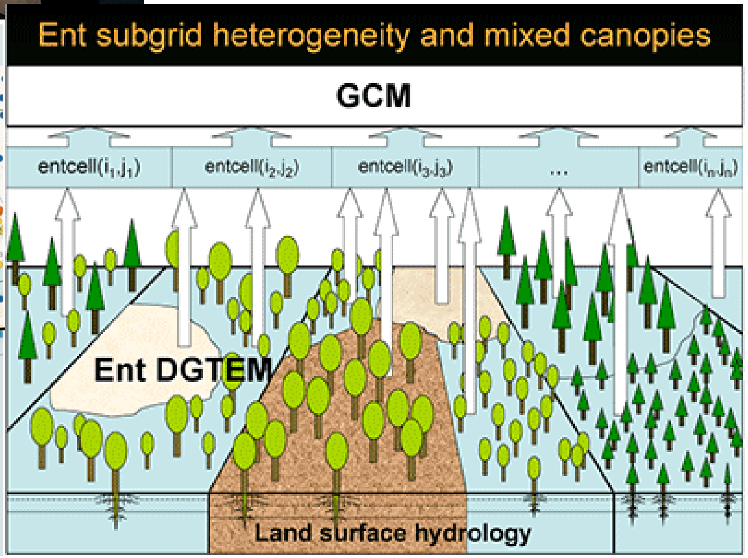




Why do we care about system sizes and overall cloud shield area?

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





Tropical Anvil Cloud Area Coupled with the ITCZ

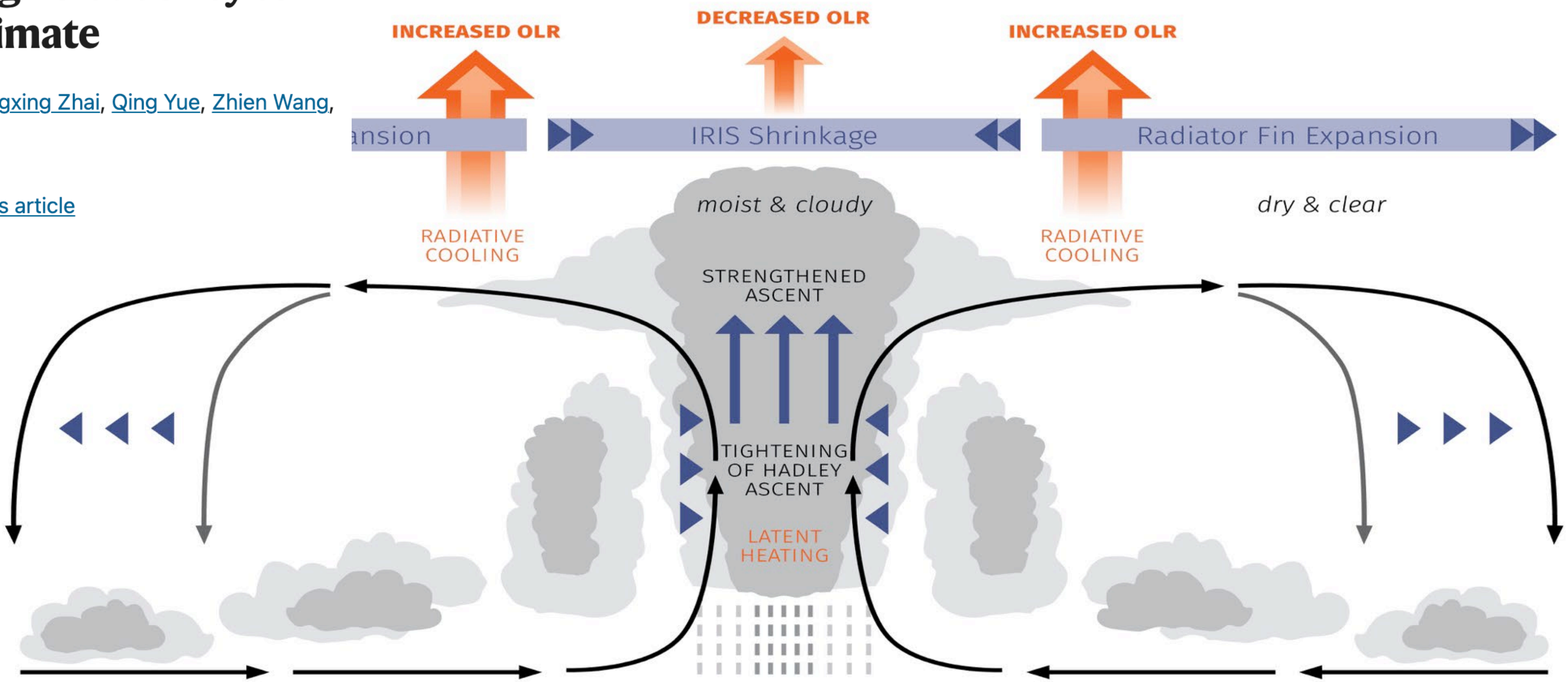
nature > nature communications > articles > article

Open Access | Published: 07 June 2017

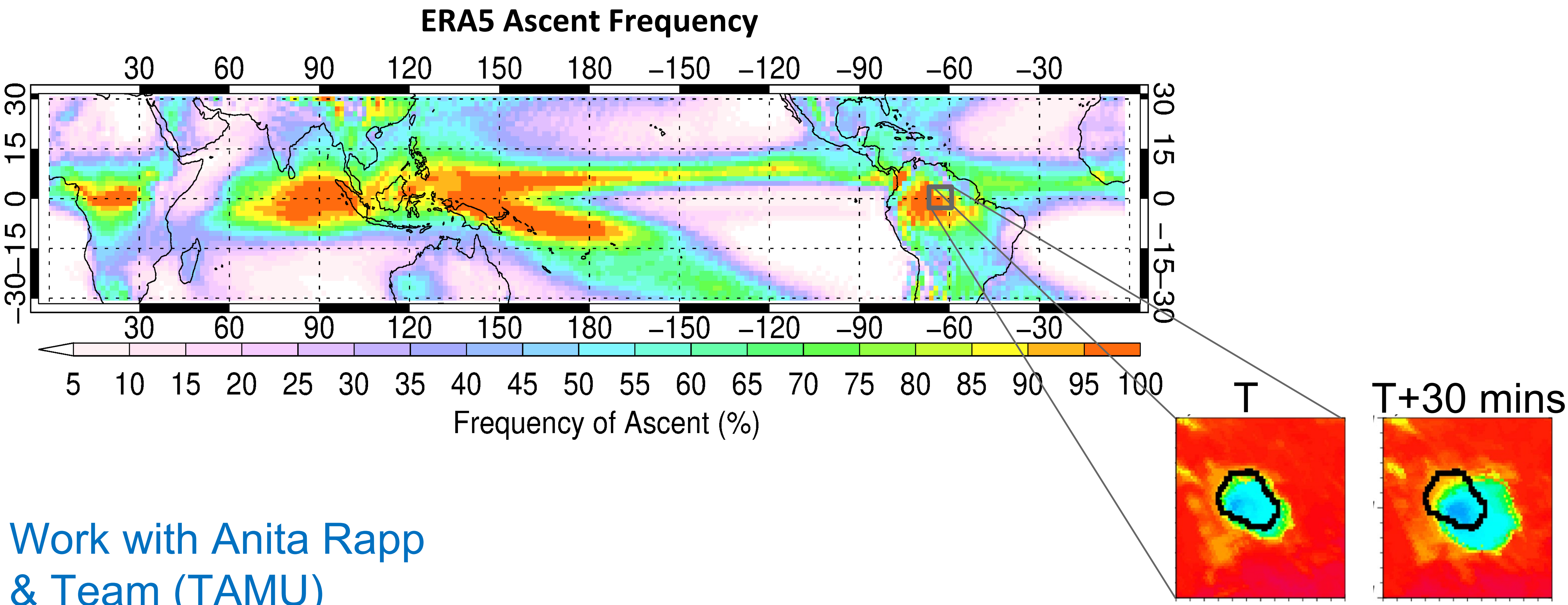
Tightening of tropical ascent and high clouds key to precipitation change in a warmer climate

Hui Su, Jonathan H. Jiang, J. David Neelin, T. Janice Shen, Chengxing Zhai, Qing Yue, Zhien Wang, Lei Huang, Yong-Sang Choi, Graeme L. Stephens & Yuk L. Yung

Nature Communications **8**, Article number: 15771 (2017) | Cite this article



Tropical Anvil Cloud Area Coupled with the ITCZ

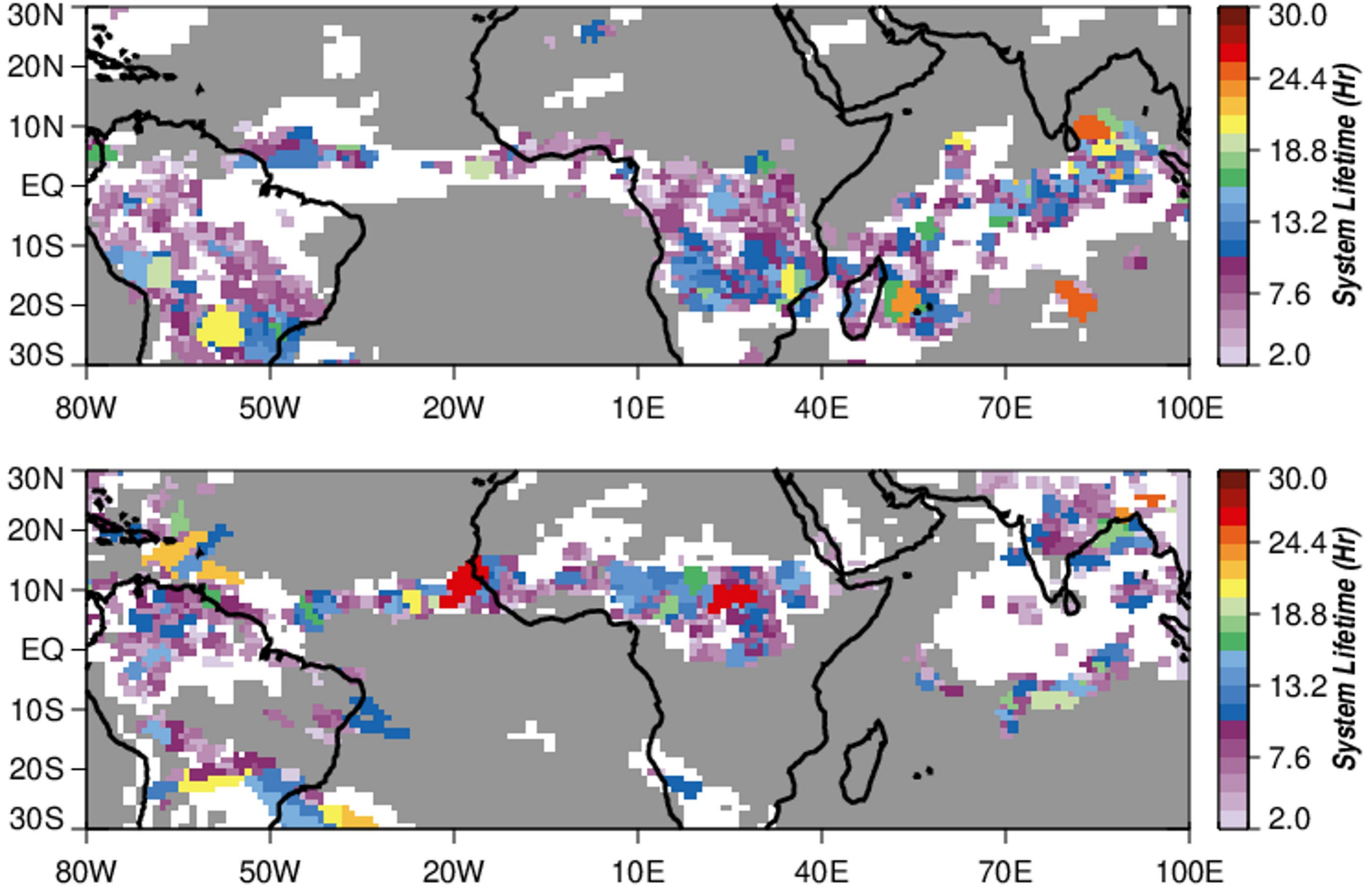


Work with Anita Rapp
& Team (TAMU)

Tropical Anvil Cloud Area Coupled with the ITCZ

Qualitative correspondence between system cloud shields observed from space and the ITCZ/ascent region.

Snapshots of Convective Systems Cloud Shield and Monthly Ascent Regions



Work with Anita Rapp & Team (TAMU)

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

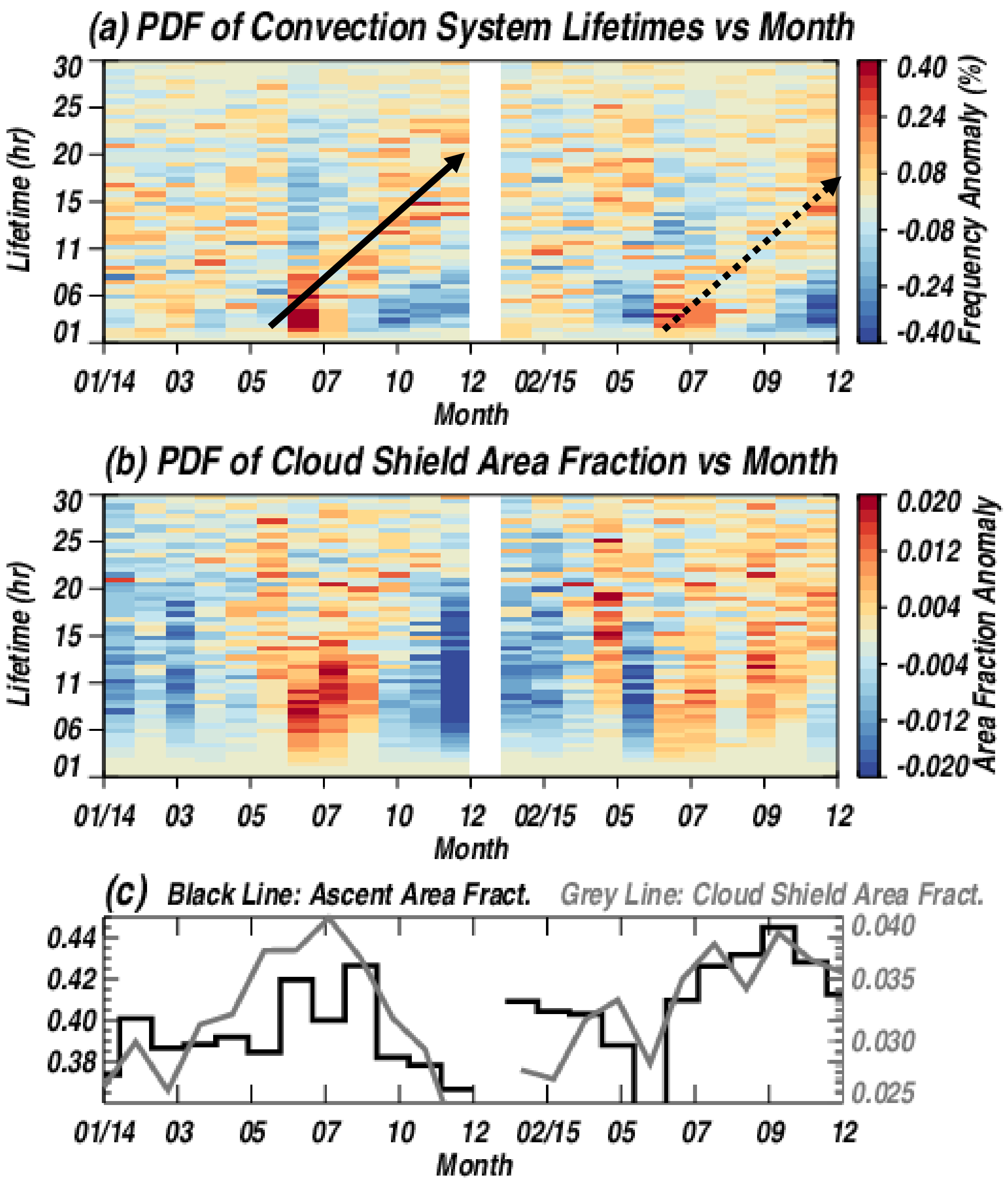
Tropical Anvil Cloud Area Coupled with the ITCZ

Can integrate tracked system anvil cloud areas to monthly scale to understand ascent region and high cloud cover variations.

$$\int^{over\ month} \frac{dA}{dt}\, dt \sim \Delta\, ITCZ\_width$$

For narrower ascent region periods, is convection more intense? What does that imply about MCS lifecyles?

Work with Anita Rapp & Team (TAMU)



COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

NASA

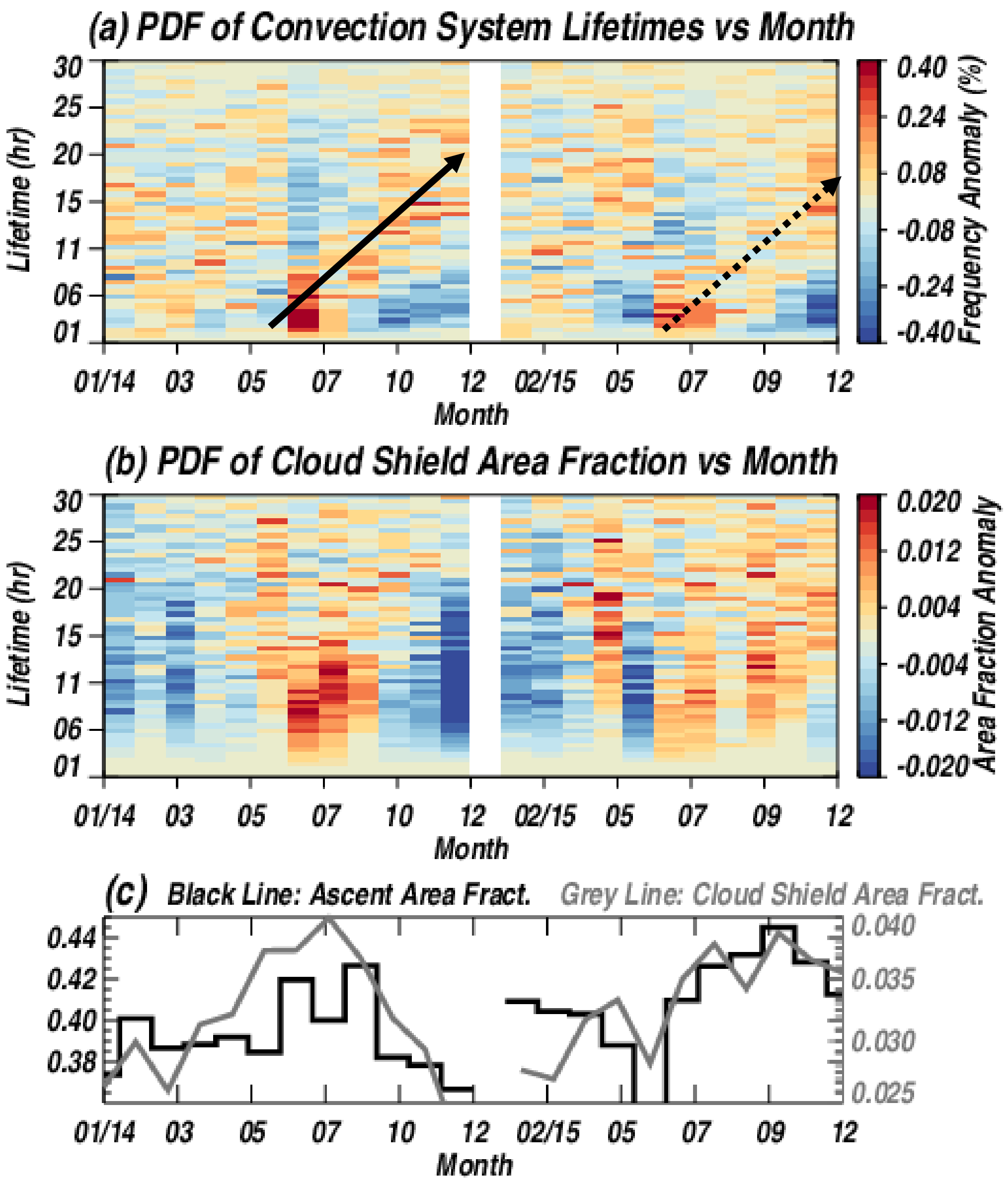
Tropical Anvil Cloud Area Coupled with the ITCZ

Can integrate tracked system anvil cloud areas to monthly scale to understand ascent region and high cloud cover variations.

$$\int_{\text{over month}} \frac{dA}{dt}\,dt \sim \Delta\, ITCZ\_width$$

For narrower ascent region periods, is convection more intense? What does that imply about MCS lifecyles?

Work with Anita Rapp & Team (TAMU)

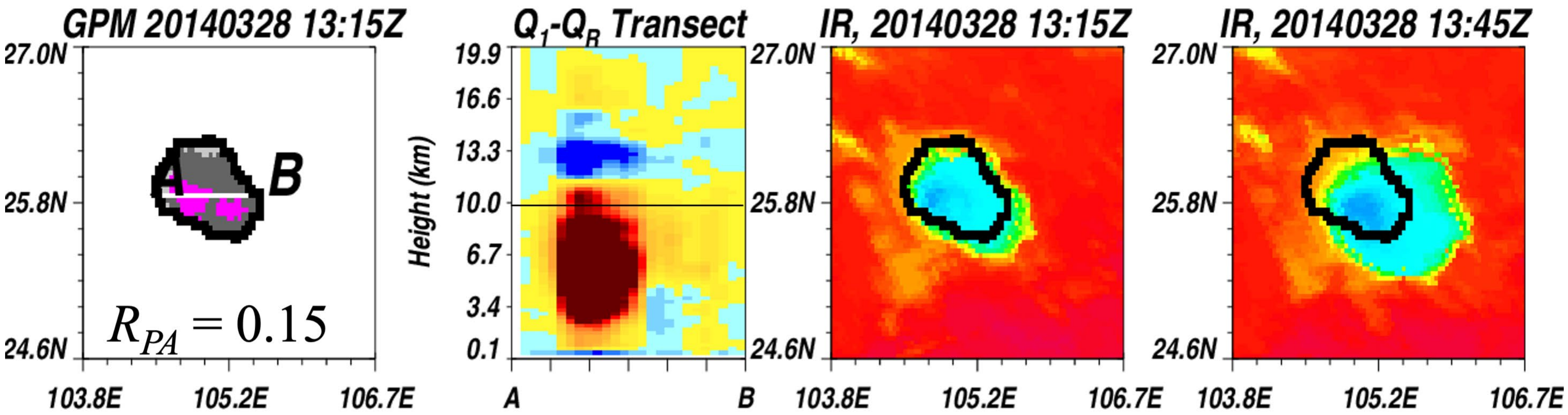


Columbia University in the City of New York

NASA

Simple Model of Convective System Area Growth Rates (Elsaesser et al. 2022, JGR -A):

1. Terms informed by satellite, WRF, & DOE/ARM data.
2. Connect tracked anvil cloud shields areas to convective mass flux, as in nature.
3. Easily implementable as an anvil cloud area parameterization?

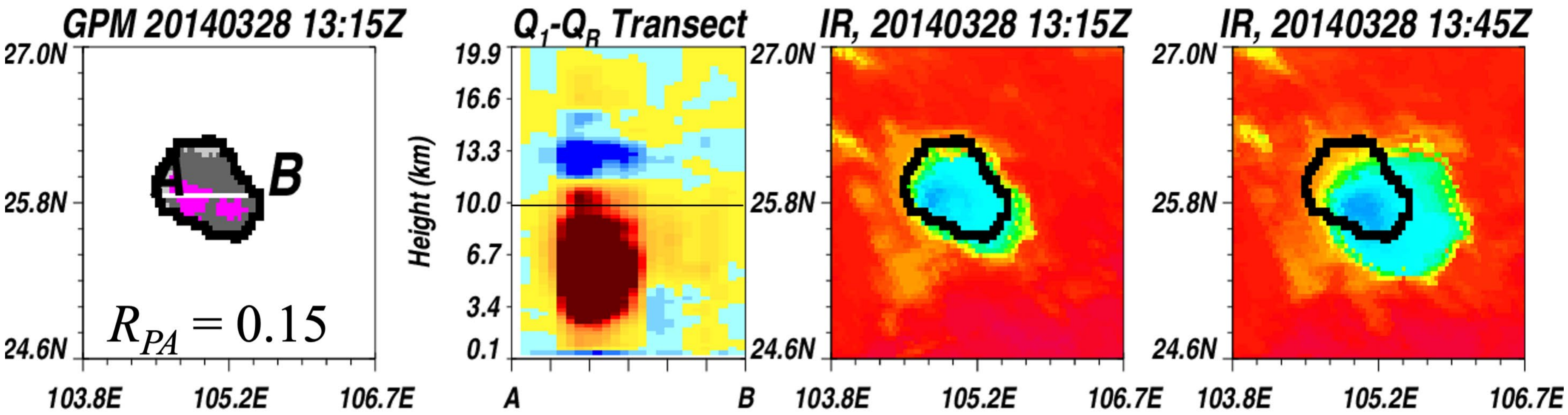


Area (A) Time Change ~ Conv. Cell Production **+ mass flux terms –** rainout/mixing

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

Simple Model of Convective System Area Growth Rates (Elsaesser et al. 2022, JGR -A):

1. Terms informed by satellite, WRF, & DOE/ARM data.
2. Connect tracked anvil cloud shields areas to convective mass flux, as in nature.
3. Easily implementable as an anvil cloud area parameterization?

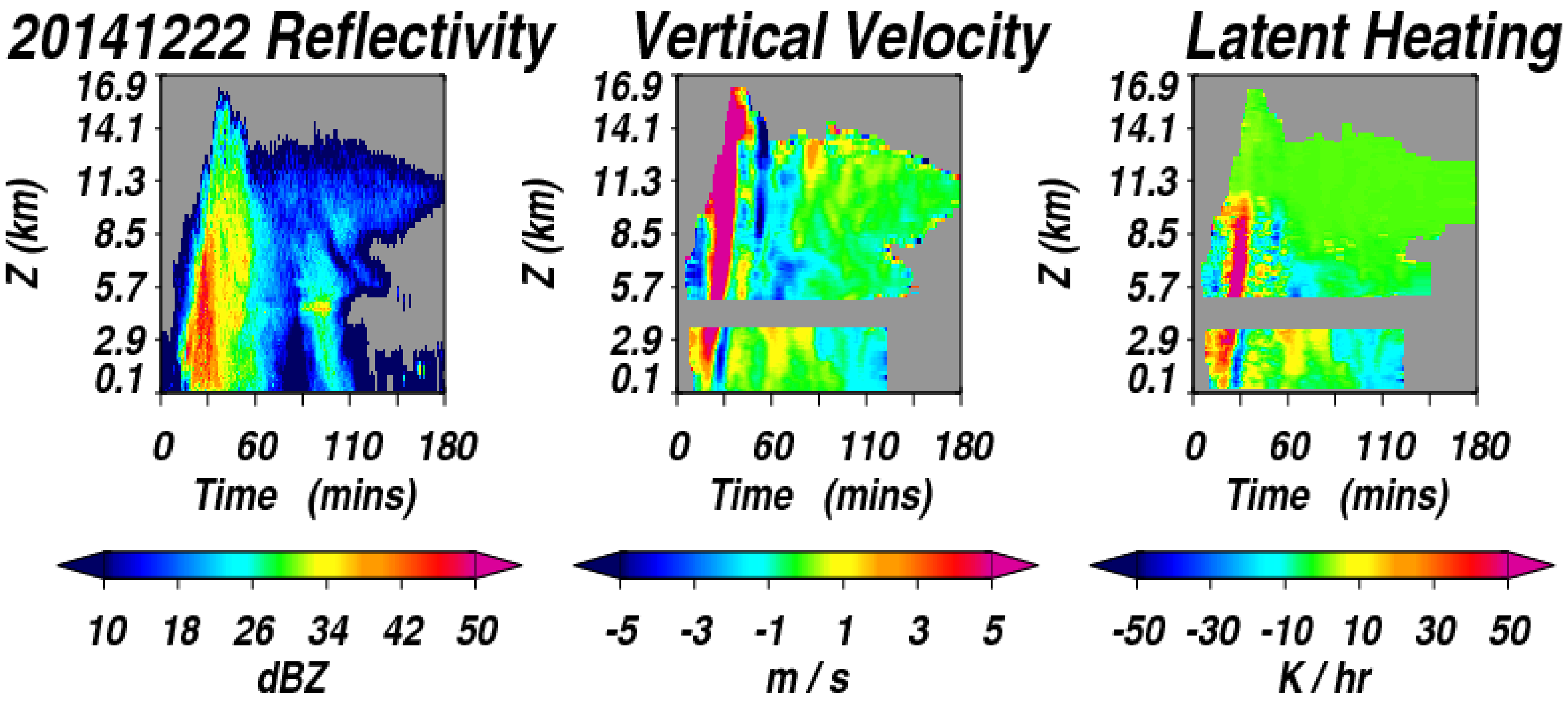


Area (A) Time Change ~ Conv. Cell Production **+ mass flux terms –** rainout/mixing

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

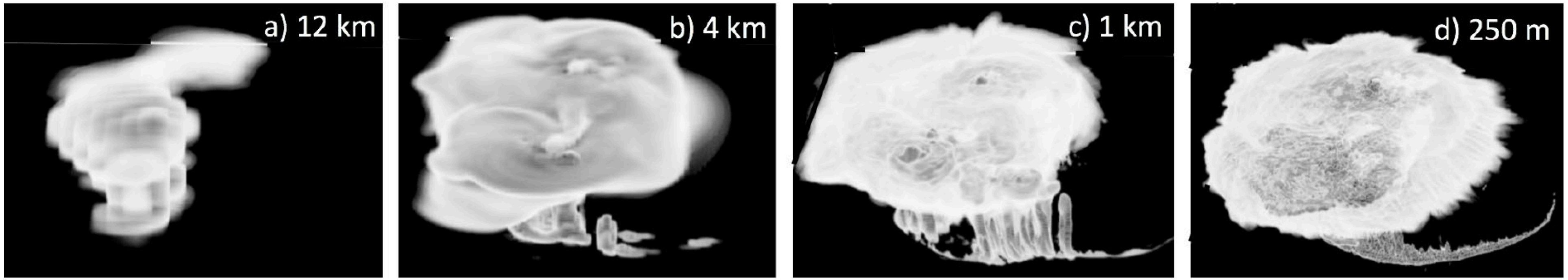
Convective mass flux is not observed over the global tropics (yet!)

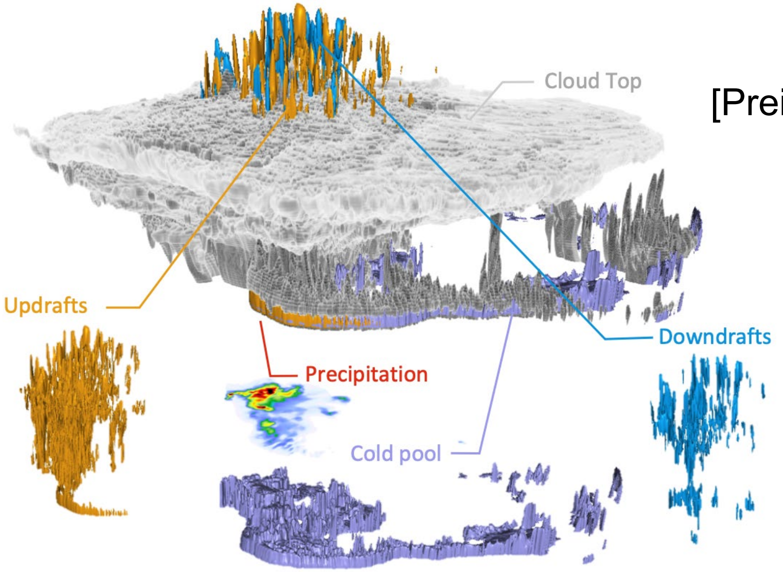
But…



Inspection of GOAmazon RWP retrievals of latent heating (LH) revealed a qualitative relationship with vertical wind not quite anticipated at such scales…

With WRF, ask: Can we infer convective mass flux at the convective system scale, or ESM grid -box scale?

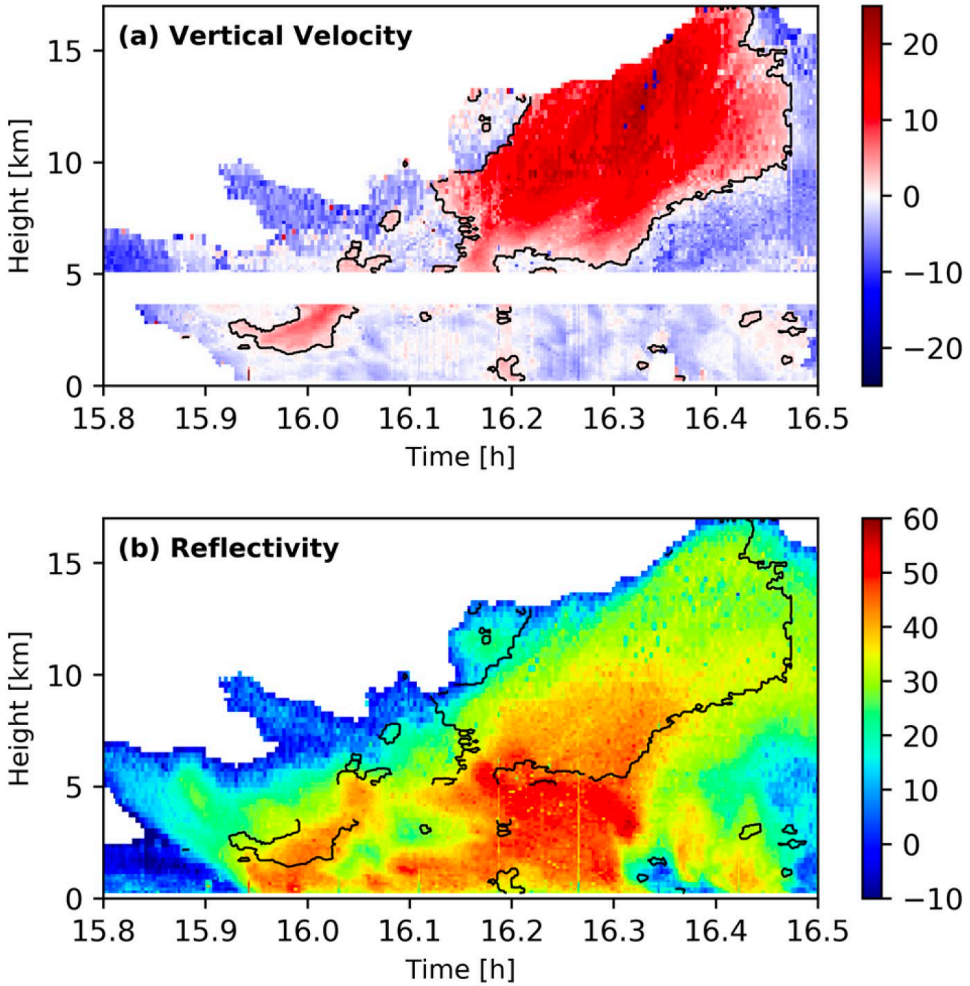




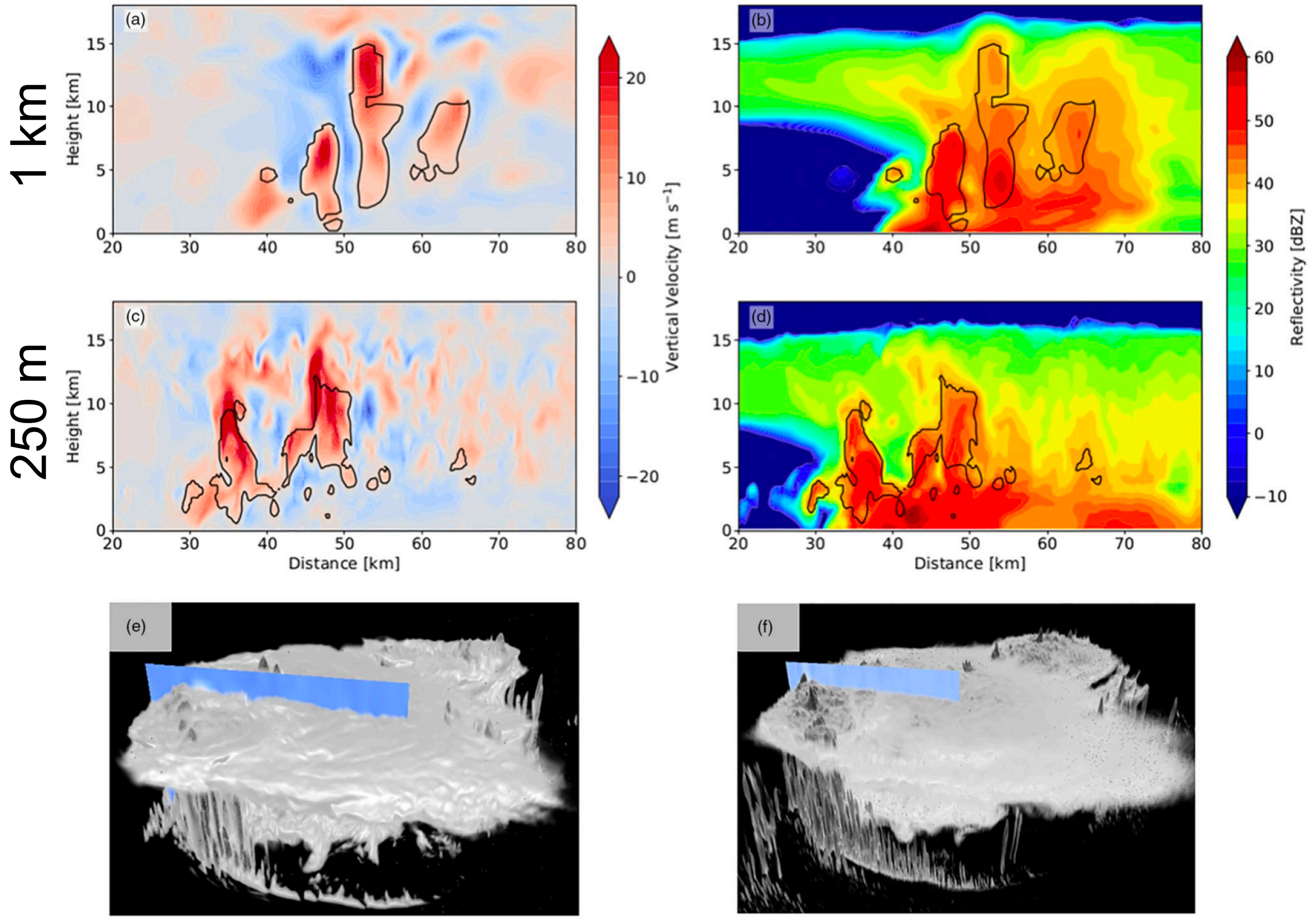
[Prein et al. 2021]

MCS figure panels provided by Andreas Prein & Team (NCAR)

But first, how are WRF convective system simulations looking?



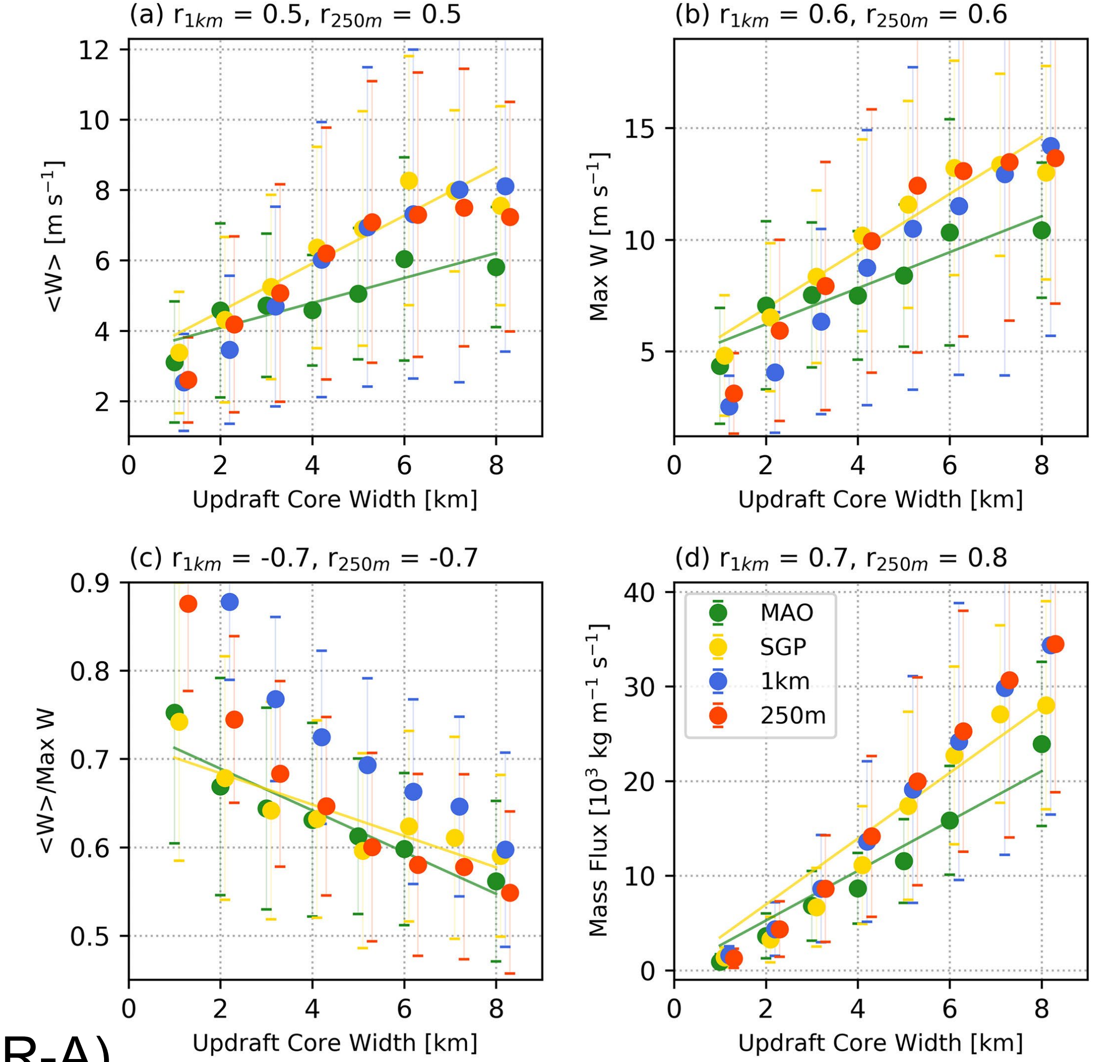
29 March 2015, MCS event during
GoAmazon2014/15 field campaign



Wang et al. (2020, JGR-A)

But first, how are WRF convective system simulations looking?

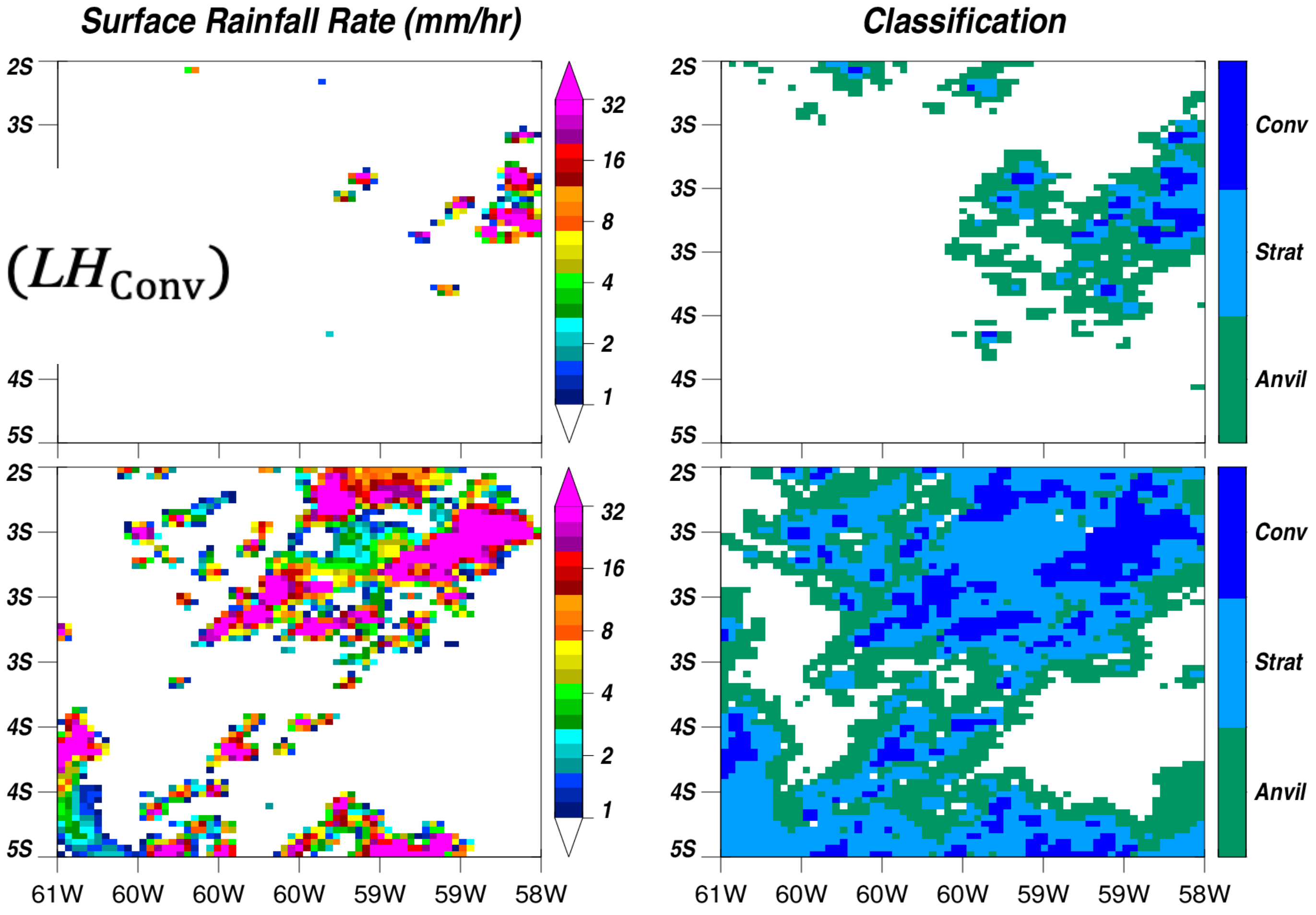
Radar Wind Profiler (RWP)

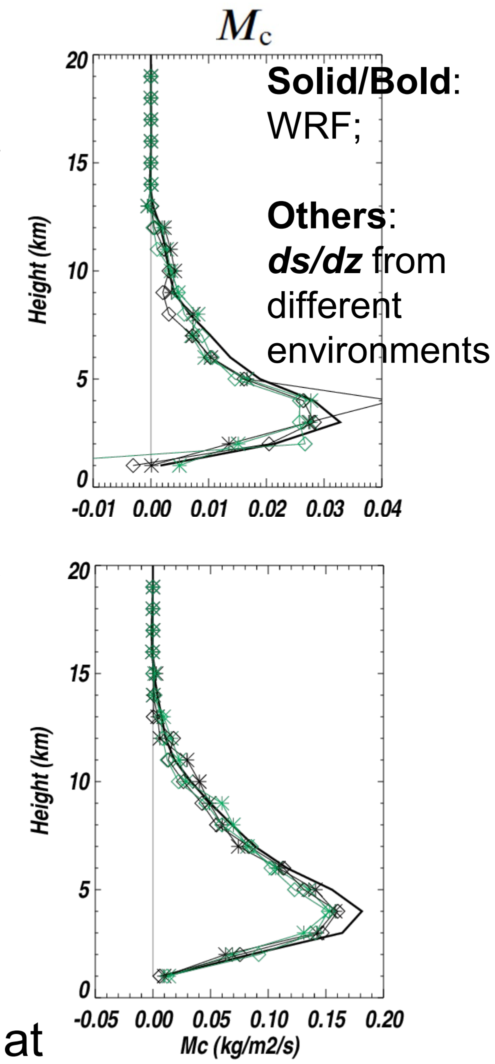


Wang et al. (2020, JGR-A)

WRF Convective Mass Flux vs Estimate from diabatic heating and T structure.

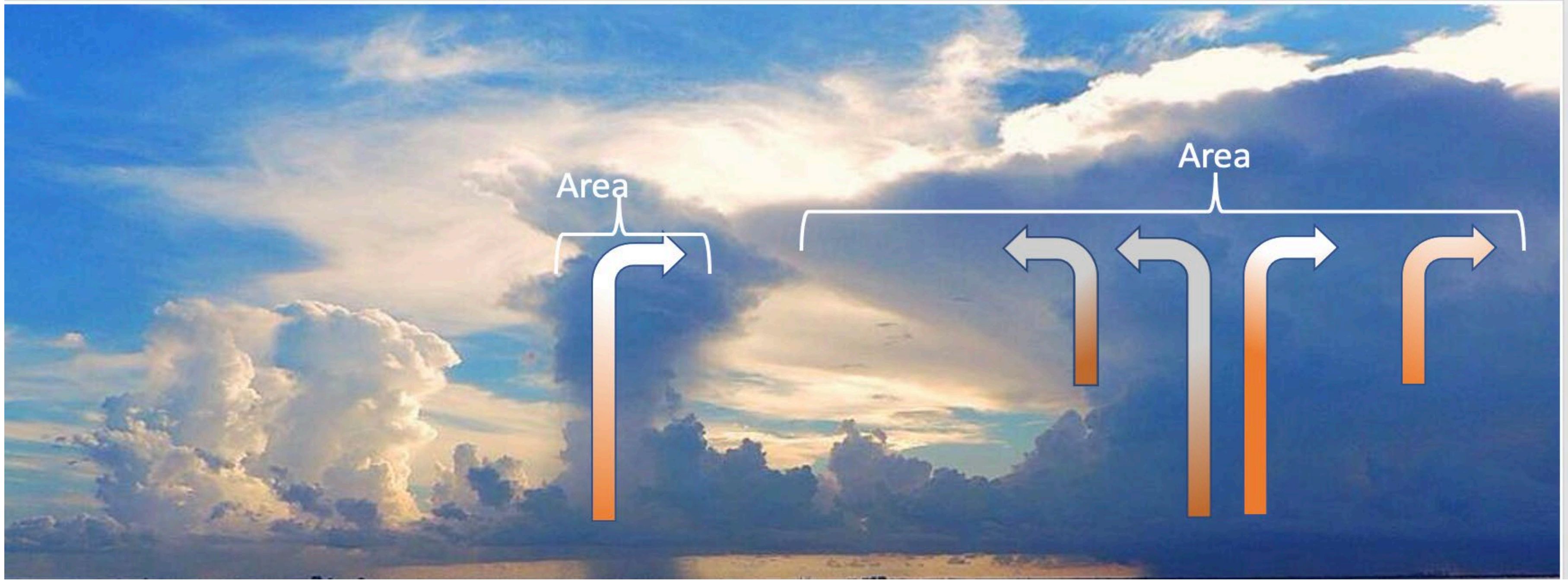
$$M_c \approx \rho A_c \left(\frac{1}{c_p} \frac{ds}{dz} \right)^{-1} (LH_{\text{Conv}})$$





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

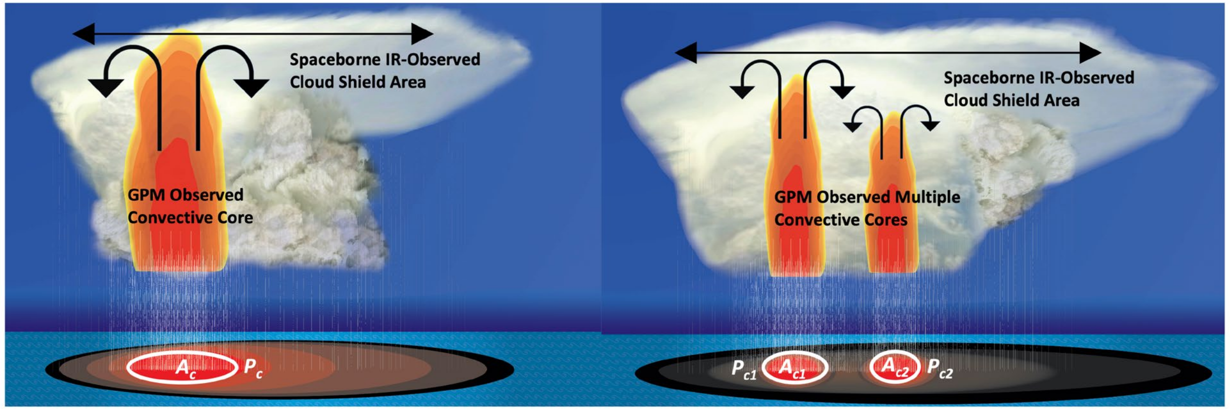
Simple Model of Convective System Area Growth Rates (Elsaesser et al. 2022, JGR -A)



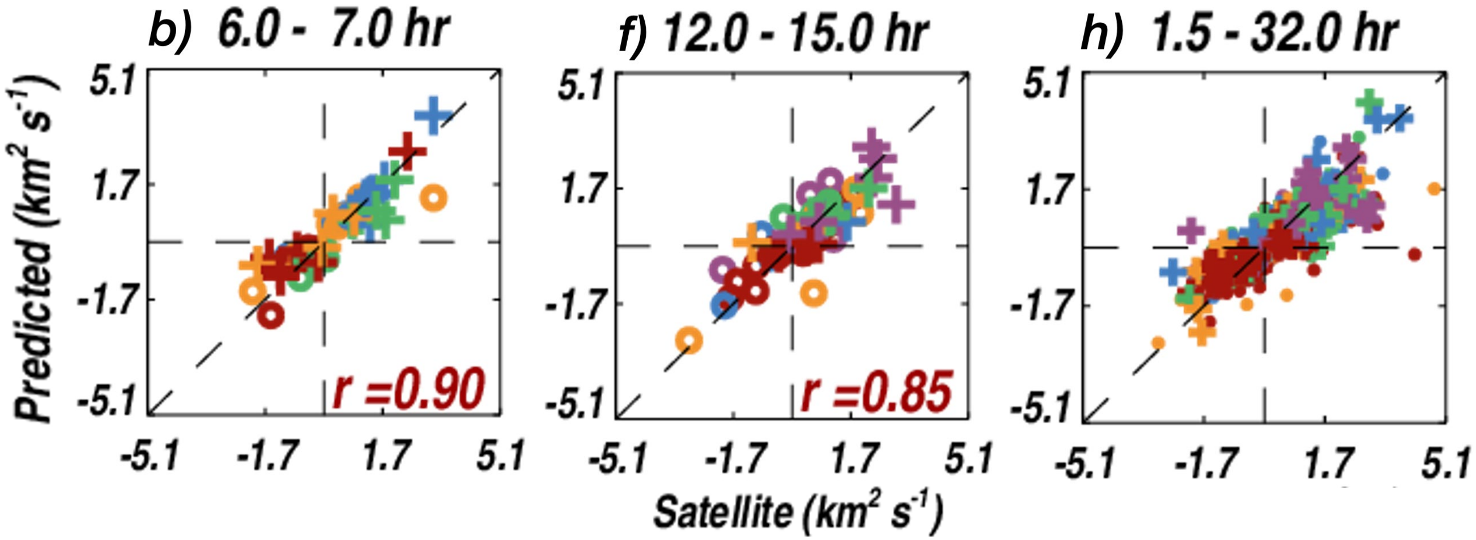
Area (A) Time Change ~ New conv. area + strat. area production – rainout/mixing

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

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



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



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}

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

Why does model work for different arrangement of convective area?

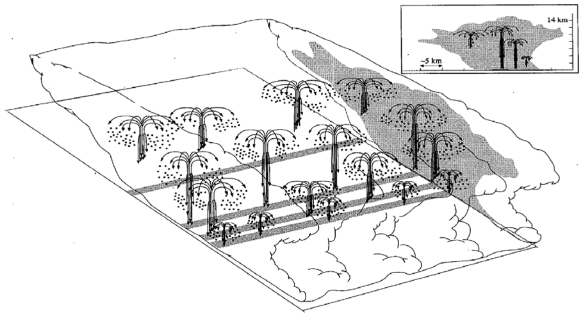
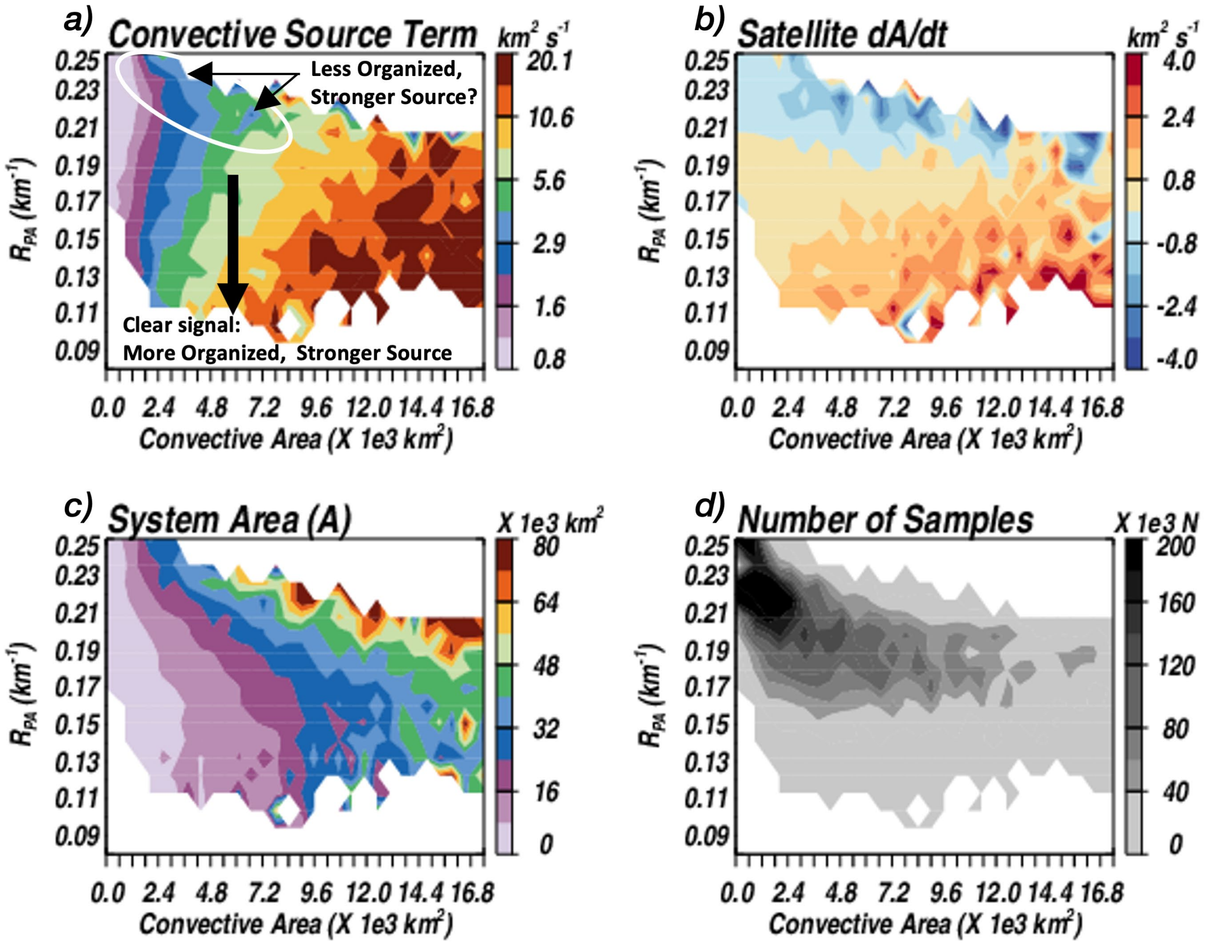


Fig. 15. Conceptual model of an ensemble of particle fountains in a multicellular storm in perspective view. Shaded area represents radar reflectivity echo along a cross section perpendicular to the line of storms. Cloud boundary indicated by scalloped outline. Inset shows approximate scales and arrangement of largest particle fountains relative to radar echo.



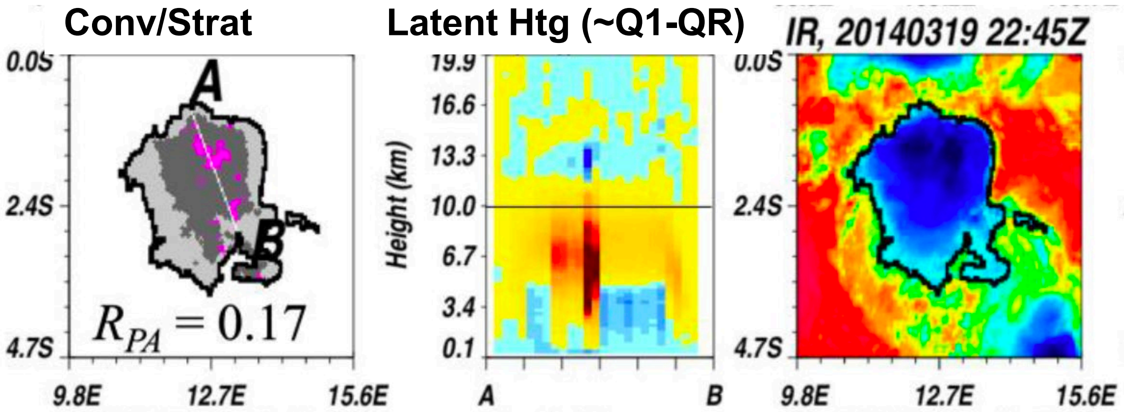
Top left : particle fountain behavior of Yuter and Houze at largest R_{PA} , spanning ~20% of data. Is this why decay rates are typically slow?

Otherwise, for a fixed convective area, forcing for shield expansion increases as cells become ***less disperse****.*

As formulated, the signal must arise from latent heating and/or lapse rates.

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

A little Convection Goes A Long Way?



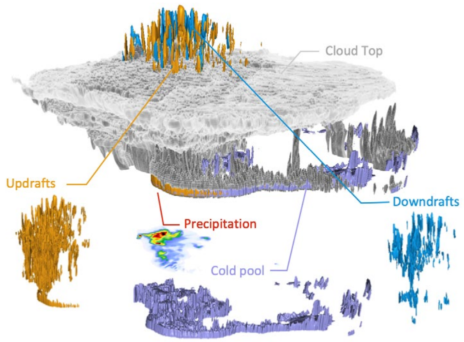
$$\frac{A_c}{A} \geq C_2 \Big/ \left(\frac{1}{\tau_{cs}} + max\left[-\frac{1}{\rho}\frac{\Delta}{\Delta z}\left(\rho \frac{Q_1\text{-}QR_{\text{Conv}}}{\Gamma - \Gamma_d} \right) \right] \right)$$

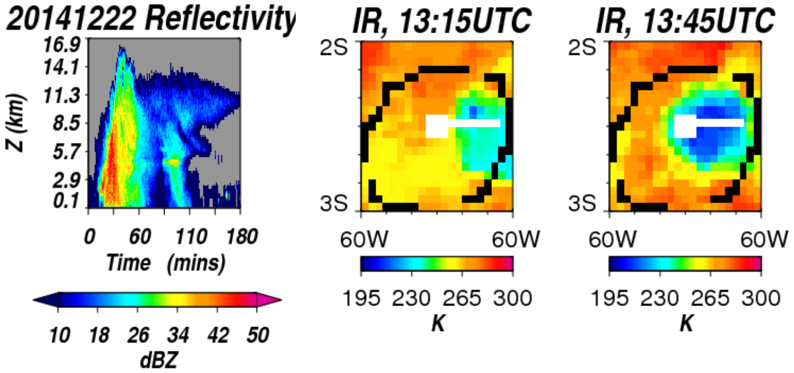
If convection occupies more than **~10-15%** of the tropical anvil cloud shield, it will grow. **But**, this depends on T lapse rates – if these change with time in the upper troposphere, so too would this threshold.

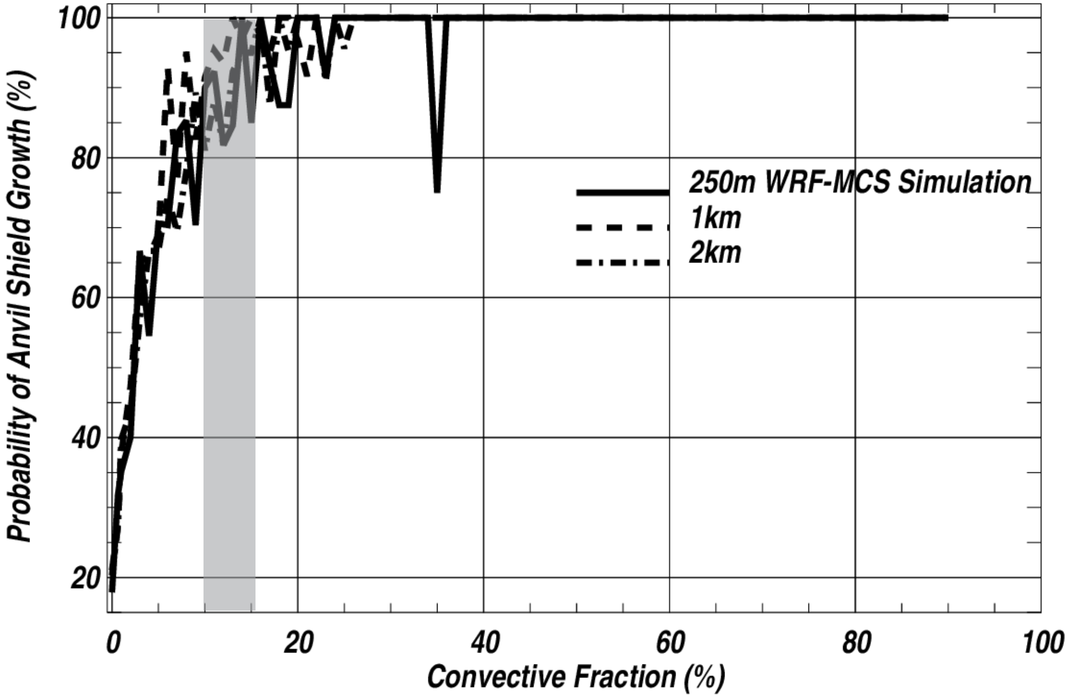
Set = to 0

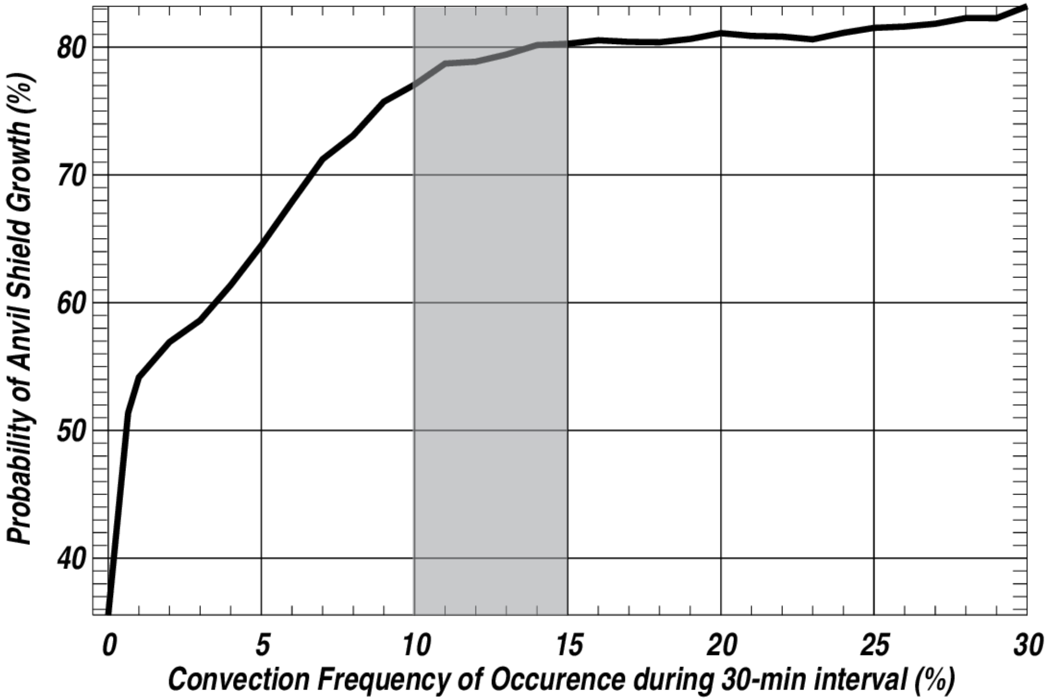
$$\frac{dA}{dt} \approx A_{c,\,\text{SRC}} - \frac{A_c}{\rho}\frac{d}{dz}\left(\rho \frac{Q_1\text{-}QR_{\text{Conv}}}{\Gamma - \Gamma_d} \right) - \frac{A}{\tau}$$

The perspective from WRF & GOAmazon / RWP at what happens to systems near 10-15% conv. coverage.









- Simple model allows for study of short timescale anvil changes with respect to upper troposphere stability and convection changes.

- Working in latent heating space enables a bridge connecting the past satellite record for latent heating, current vertical updraft speed/latent heating estimates from WRF/DOE instruments, and future (direct, global) convective mass flux observations.

- Ongoing work: understanding the anvil cloud shield decay timescale (which is short, ~2-3 hours). Environment and/or stratiform rainfall driven? …and, extension to higher latitudes.

WRF--DOE/ARM--Satellite "Trifecta of Approaches" critical.

Thanks!