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.

Grid-box stratiform rainfall (mm/hr) vs. Grid-box convective rainfall (mm/hr)

**GPM**
- Count: 0.10
- r = 0.71

**GISS-E3dev Bin Counts**
- Count: 0.10
- r = 0.15

No MCSs? Anvils coupled to cores?
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 $\sim$ Conv. Cell Production + mass flux terms – rainout/mixing

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

https://doi.org/10.1029/2021JD035599
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\[
\frac{dA}{dt} \approx A_{c, \text{SRC}} - \frac{1}{\rho} \frac{dM_c}{dz} - \frac{1}{\rho} \frac{dM_s}{\alpha z} - \frac{A}{\tau} \times
\]

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

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

Area (A) Time Change $\sim$ Conv. Cell Production + mass flux terms $-$ rainout/mixing

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

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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 heating ($Q_1 = LH + QR + \text{eddy}$, averaged across convective cores) is very related to $M_c$ at all levels. Dominant term? : **Latent Heating (LH)**

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

Solid: WRF; Lines with symbols: ds/dz from different environments
Simple Model of Convective System Area Growth Rates

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

Area (A) Time Change \sim \text{New conv. area} + \text{strat. area production} - \text{rainout/mixing}
**Simple Model of Convective System Area Growth Rates**

\[
\frac{dA}{dt} \approx A_{C, SRC} + \frac{A_C}{\rho} \frac{d}{dz} \left( \frac{Q_{1} - Q_{R,Conv}}{\Gamma - \Gamma_d} \right) - \frac{A}{\tau}
\]

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

GEO-IR (TOOCAN MCSs)  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)

\[
\frac{dA}{dt} \approx A_{c, SRC} - \frac{A_c}{\rho} \frac{d}{dz} \left( \rho \frac{Q_l - Q_{R_{Conv}}}{\Gamma - \Gamma_d} \right) - \frac{A}{\tau}
\]
Model does well in different convective aggregation states, over land vs ocean, and for different convective system life stages.

\[ R_{PA} = 0.25 \]

\[ R_{PA} = 0.15 \]

\[ \frac{dA}{dt} \approx A_{c, SRC} - \frac{A_c}{\rho} \frac{d}{dz} \left( \frac{Q_l - Q_{RConv}}{\Gamma - \Gamma_d} \right) - \frac{A}{\tau} \]
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.

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

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: