How does convective self-aggregation impact precipitation extremes?

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With funding from
Recent trends in tropical precipitation linked to organization

**Mesoscale Convective System**

Change in monthly mean precipitation (1998 to 2009)

- Contribution from changes in frequency of organized deep convection
- Contribution from other convective regimes

[Tan et al, Nature 2015]
Self-aggregation of deep convection

- SAM [Khairoutdinov & Randall 03]
- SST=300K uniform
- No Coriolis (f=0)
- Doubly periodic
- No large-scale forcing
- In RCE

Clouds over near-surface temperature in cloud-resolving model SAM

Self Aggregation = Instability of disorganized Radiative-Convective Equilibrium “pop corn” state

Question addressed

How does convective self-aggregation impact precipitation extremes?
Why?
How does convective self-aggregation impact precipitation extremes? Why?

How does convective self-aggregation change with warming?

Sara Shamekh poster A27 session 1
Self-aggregation leads to enhanced moisture variability (moister moist region, drier dry region)

- Overall drying
- Overall warming (warmer moist adiabat)

[Muller & Held, JAS 2012]
Precipitation extremes with self-aggregation

⇒ increased instantaneous precipitation extremes (even more when time-accumulate)

consistent with [Bao Sherwood 2019]
Precipitation extremes with self-aggregation

\[ + 20\% \text{ increase} \]

\[ + 20\% \text{ increase of instantaneous precip extremes} \]

(large variability with aggregation)

Why 20\%?
Theoretical scaling for precipitation extremes

\[ \delta P \sim \delta \left( \varepsilon_p \int \rho w \left( -\frac{\partial q_{sat}}{\partial z} \right) dz \right) \]

Precip efficiency \hspace{1cm} Condensation

Dynamic \hspace{1cm} Thermodynamic

[Mueller Takayabu 2019]
Theoretical scaling for precipitation extremes

\[ \delta P \sim \delta \left( \varepsilon_p \int \rho w \frac{-\partial q_{sat}}{\partial z} \, dz \right) \]

- Condensation rate: -15%
- Dynamic: -20%
- Thermodynamic: +5%

Precip efficiency: +20%
Theoretical scaling for precipitation extremes

Increasing near-cloud boundary layer moisture
- Positive but small contribution

Boundary layer water vapor increase with aggregation (~ +10%)

Thermodynamic contribution linked to boundary layer water vapor

Increase due to moister near-cloud boundary layer

Positive but small contribution

[Müller 2013]
Theoretical scaling for precipitation extremes

Decrease in CAPE with aggregation (-40%)

Moister near-cloud conditions
⇒ less entrainment effect
⇒ Atmosphere closer to undilute temperature profile

Negative dynamic contribution consistent with decreased CAPE
Theoretical scaling for precipitation extremes

Precip efficiency

\[ \delta P \sim \delta \left( \varepsilon_p \int \rho w \left( -\frac{\partial q_{sat}}{\partial z} \right) dz \right) \]

Thermodynamic
Condensation
Dynamic

-15% +35% -20% +5%

Precip efficiency +35%
Theoretical scaling for precipitation extremes

Efficiency $\varepsilon=\alpha(1-\beta)$ [Lutsko Cronin 2018]

Cloud condensate $q_n \rightarrow$ precipitating condensate $q_p \rightarrow$ surface precipitation

- $+7\% \left( \int q_p / \int q_n \right)$
- $+25\% \left( Pr_{sfc} / Pr_{max} \right)$

$\Rightarrow$ Reduced rain evaporation with aggregation dominates

- Due to moister conditions, and
- Faster terminal velocities from warmer temperatures (more rain less snow; no change in graupel)
Conclusions

• Self-aggregation yields increased precipitation extremes

• Thermodynamic contribution positive but small
  Due to moister near-cloud boundary layer

• Dynamic contribution negative
  Due to decreased entrainment effects, thus decreased CAPE

• Precip efficiency contribution positive and largest
  Dominated by reduced evaporation of rain, from moister and warmer conditions (latter => faster terminal velocities)

The contribution from organized convection to precip extremes is important (compare to 7%/K increase in « pop corn » convection »

[Da Silva, Shamekh, Muller 2019 (in prep.)]