Hailstorm Modeling

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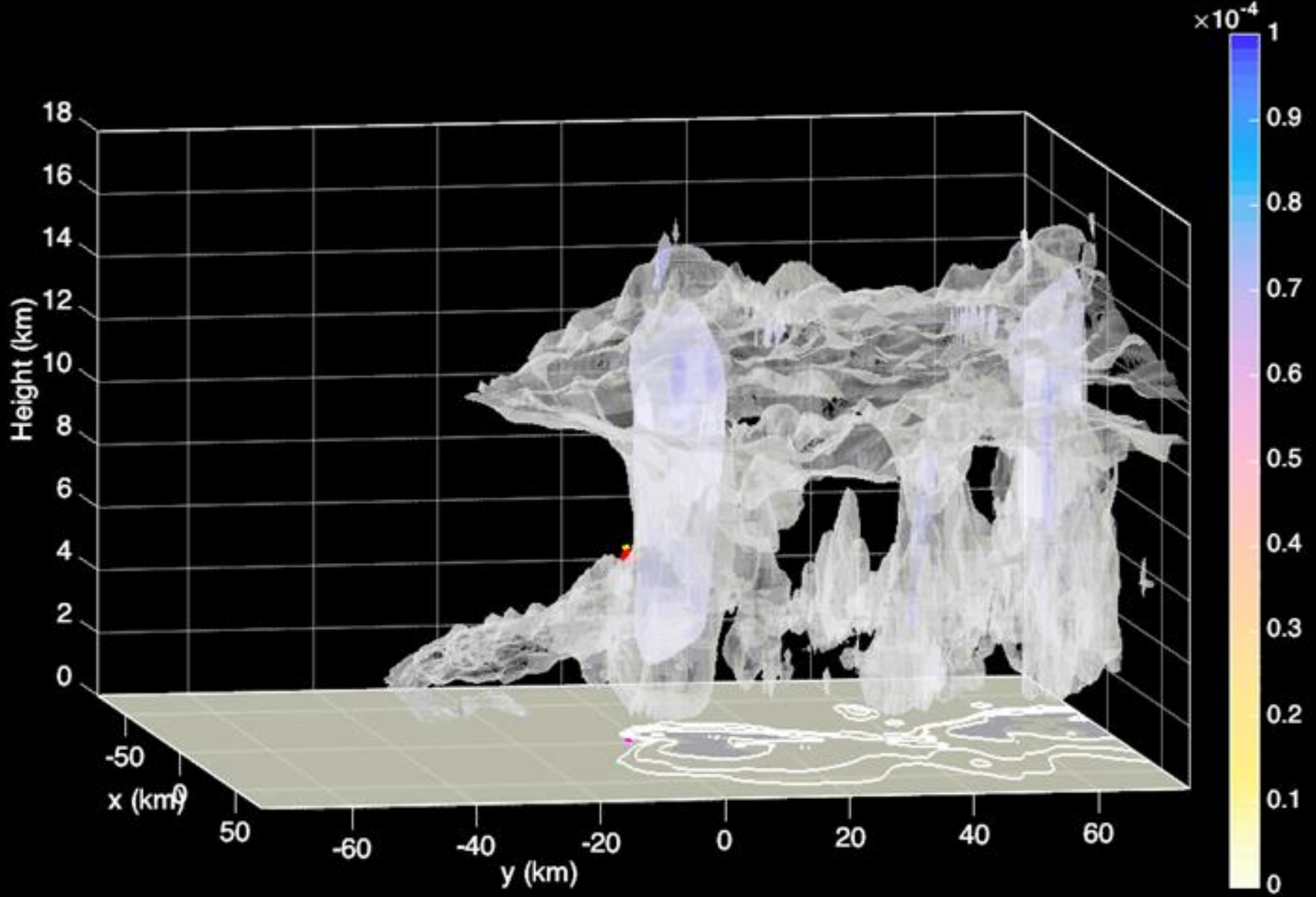

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CIWRO Virtual Workshop on Mesoscale & Storm Scale Meteorology
6 December 2021

Why Hail?

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- Hail is the most costly hazard from severe convective storms, causing ~$10B in damage annually (*Insurance Institute for Business and Home Safety, 2018*)
- Commonly used environmental parameters (CAPE, shear, LHP) **do not** discriminate hail sizes well (*e.g., Edwards & Thompson 1998; Jewell and Brimelow 2009; Johnson & Sugden 2014; Pučik et al. 2015; Taszarek et al. 2017; Allen et al. 2021; Gutierrez & Kumjian 2021*)
- Hail reports databases **leave much to be desired** (*e.g., Dotzek et al. 2009; Allen et al. 2015; Giammanco et al. 2018*)
- NWS forecasts and warnings consistently underestimate maximum hail sizes (*e.g., Blair et al. 2011, 2017*)

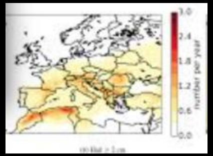
A Primary Objective:

*Investigate the **environmental** and **internal storm** controls on hail growth*

US. Storm Prediction Center

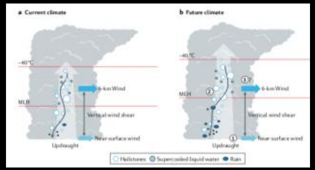
Forecasting

Hailstorm proxies



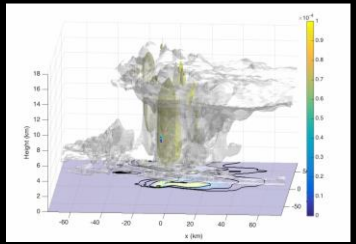
Rädler et al. (2018)

Climate change impacts on hail



Raupach et al. (2021)

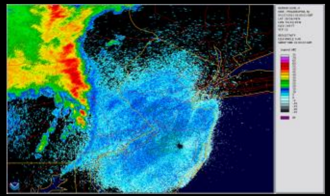
Hailstorm modeling



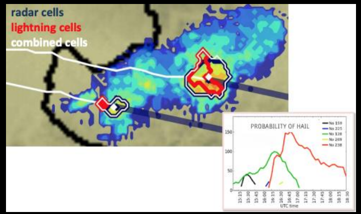
Microphysical processes

Rasmussen et al. (1984)

Remote sensing



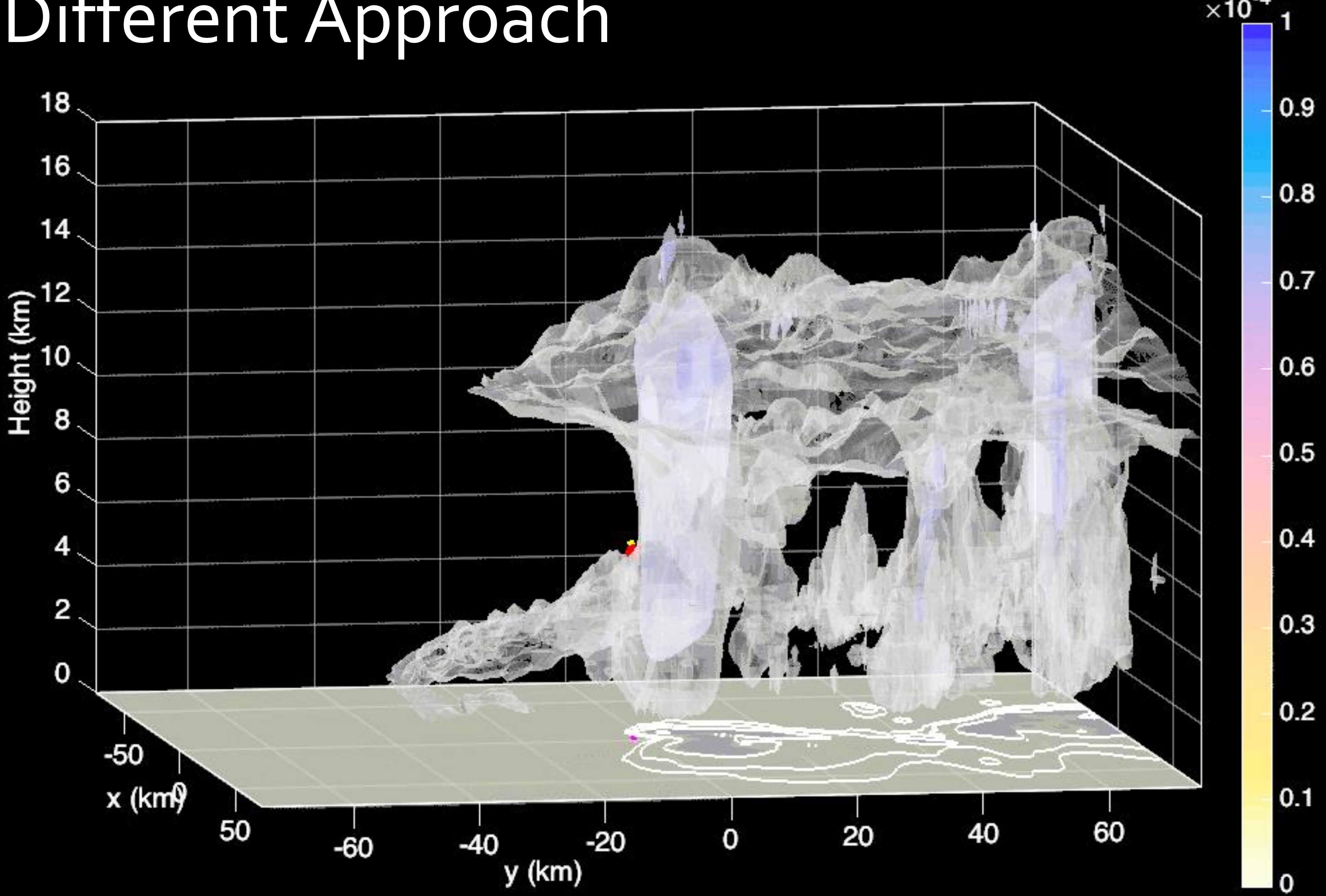
U.S. National Weather Service



Nowcasting

Meyer & Tüchler (2021)

A Different Approach



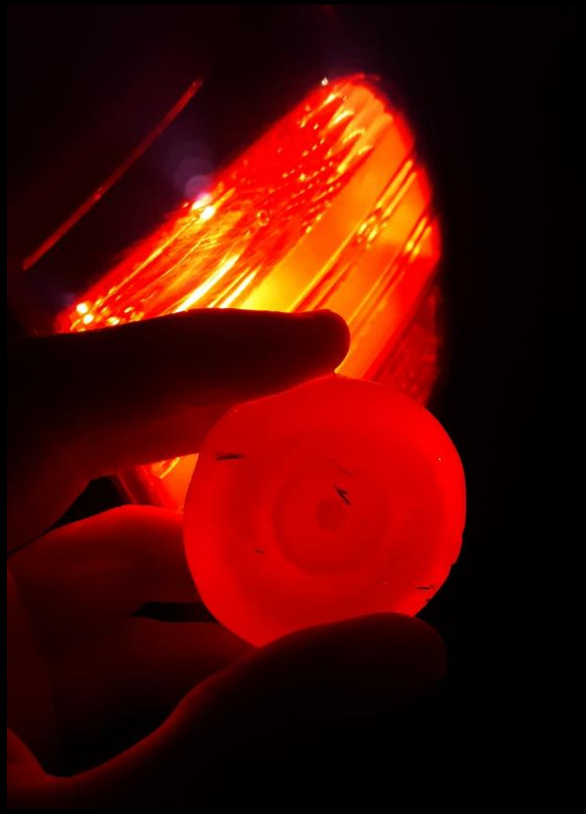
(Dennis & Kumjian 2017; Kumjian and Lombardo 2020; Kumjian, Lombardo, Loeffler 2021; Lin and Kumjian 2021)

Methods

Hailstorm Modeling w/ Explicit Hailstone Trajectory Model

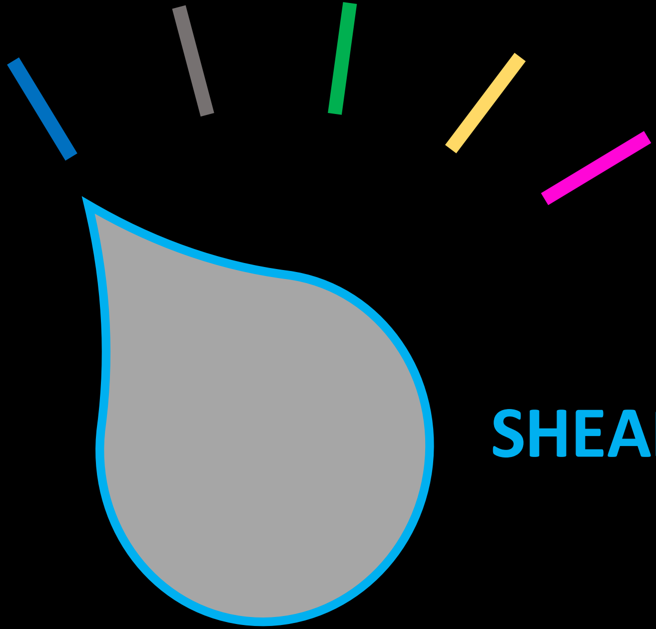
- **Microphysical processes** calculated explicitly from storm-scale simulation fields

  - Collection of supercooled raindrops and cloud droplets
    - Continuous collection, parameterized cloud droplet collection efficiency
    - Variable rime density following Heymsfield and Pflaum (1985), with modifications
  - Collection of ice crystals and snow (during wet growth only)
  - Sublimation/deposition
  - Soaking/retention of unfrozen accreted water (e.g., Ziegler et al. 1983; Adams-Selin & Ziegler 2016)
  - Melting & Shedding (following Rasmussen and Heymsfield 1987)
  - Reynolds-number-dependent thermal energy and vapor transfer coefficients (following Rasmussen and Heymsfield 1987, modified for nonspherical shapes)
  - Accounting for nonspherical shapes and tumbling on collection (Lin and Kumjian, *in prep*)

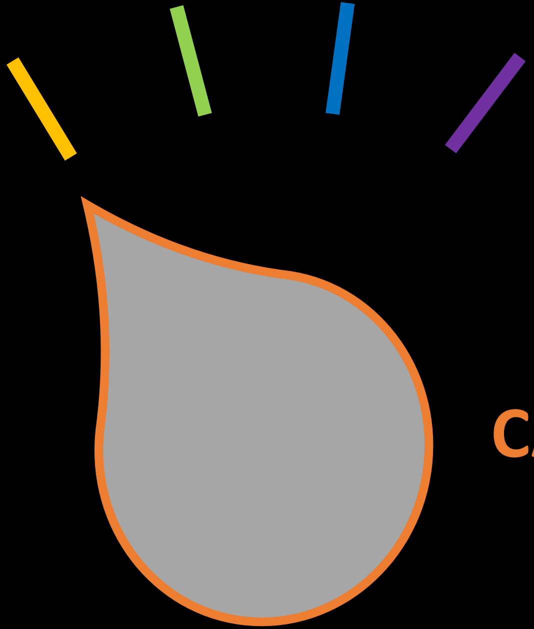


Kumjian and Lombardo (2020)

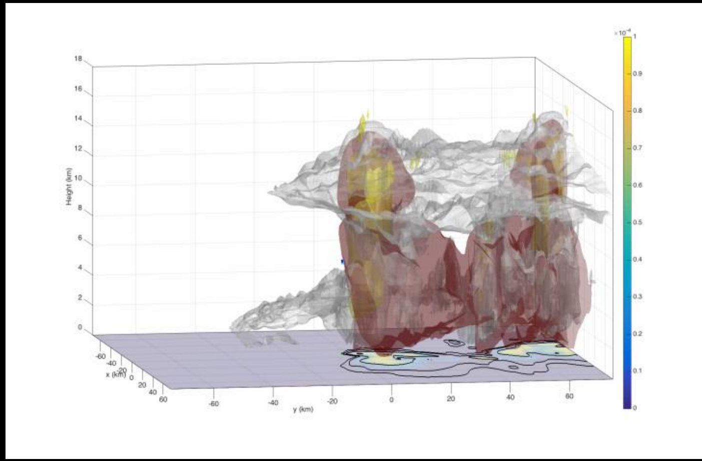
What is the effect of environmental factors like CAPE and shear on hailstorms?



SHEAR



CAPE



Impact of Vertical Wind Shear

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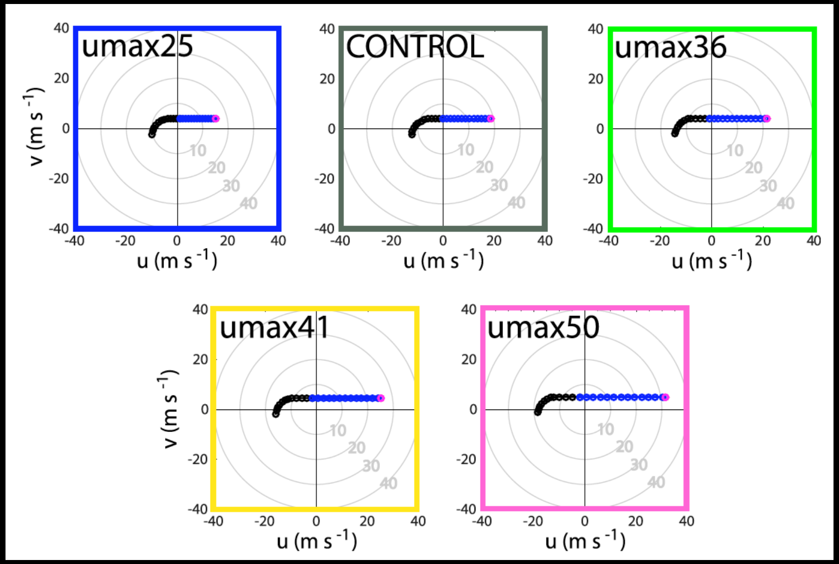
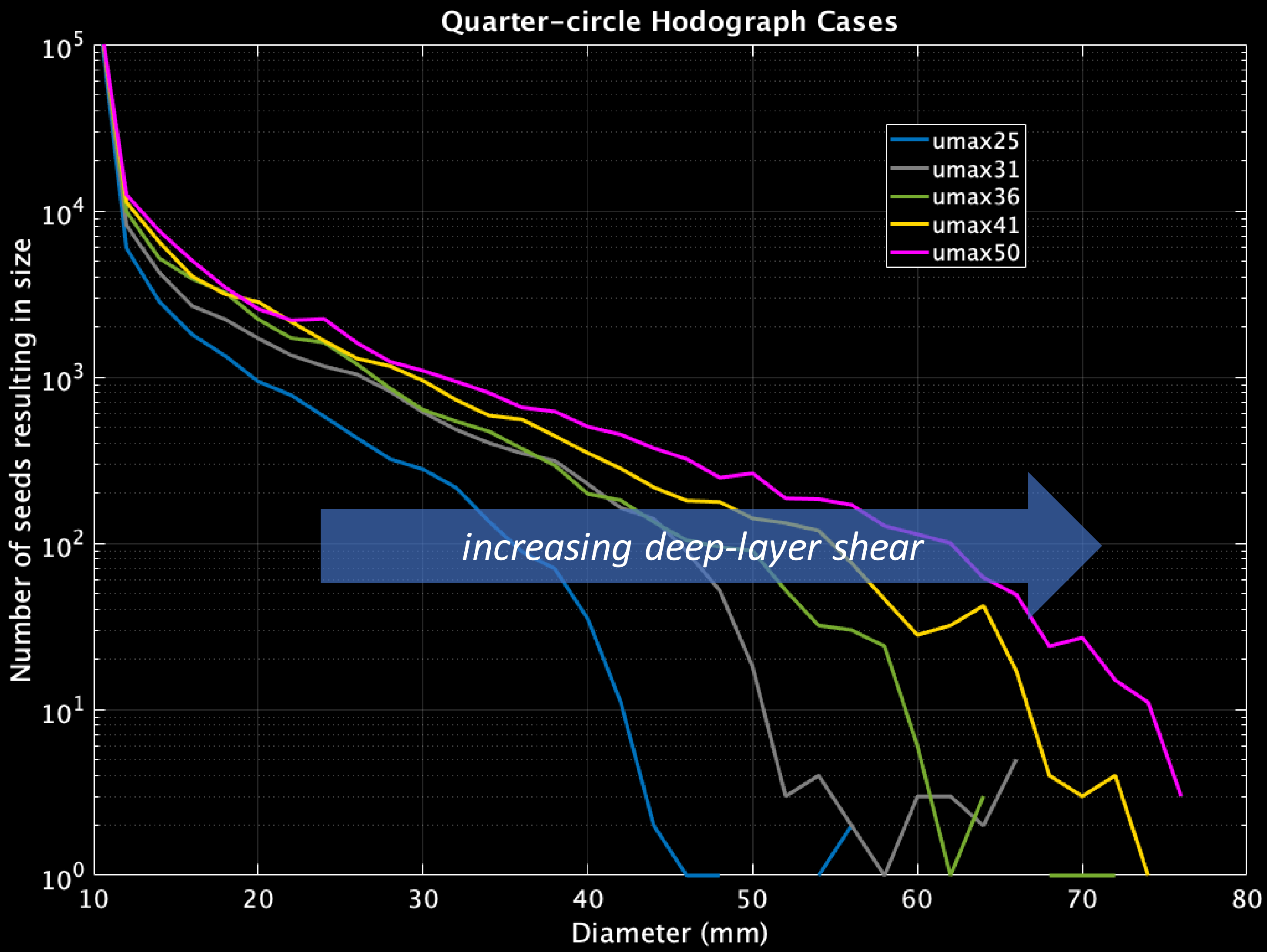
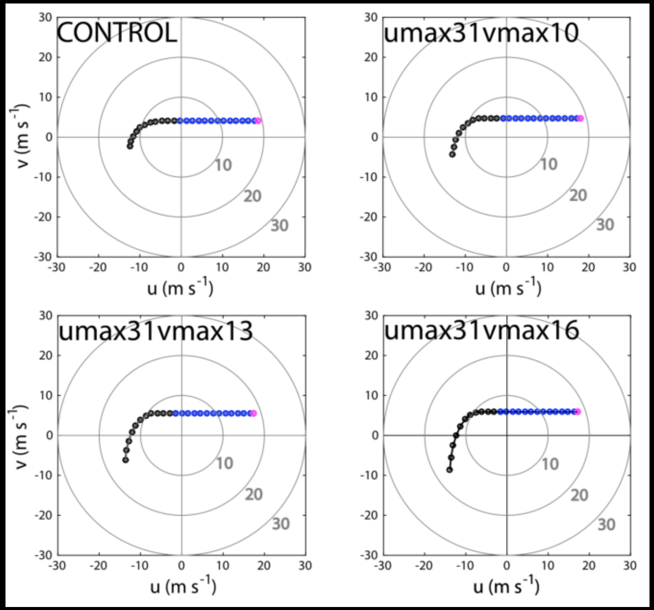


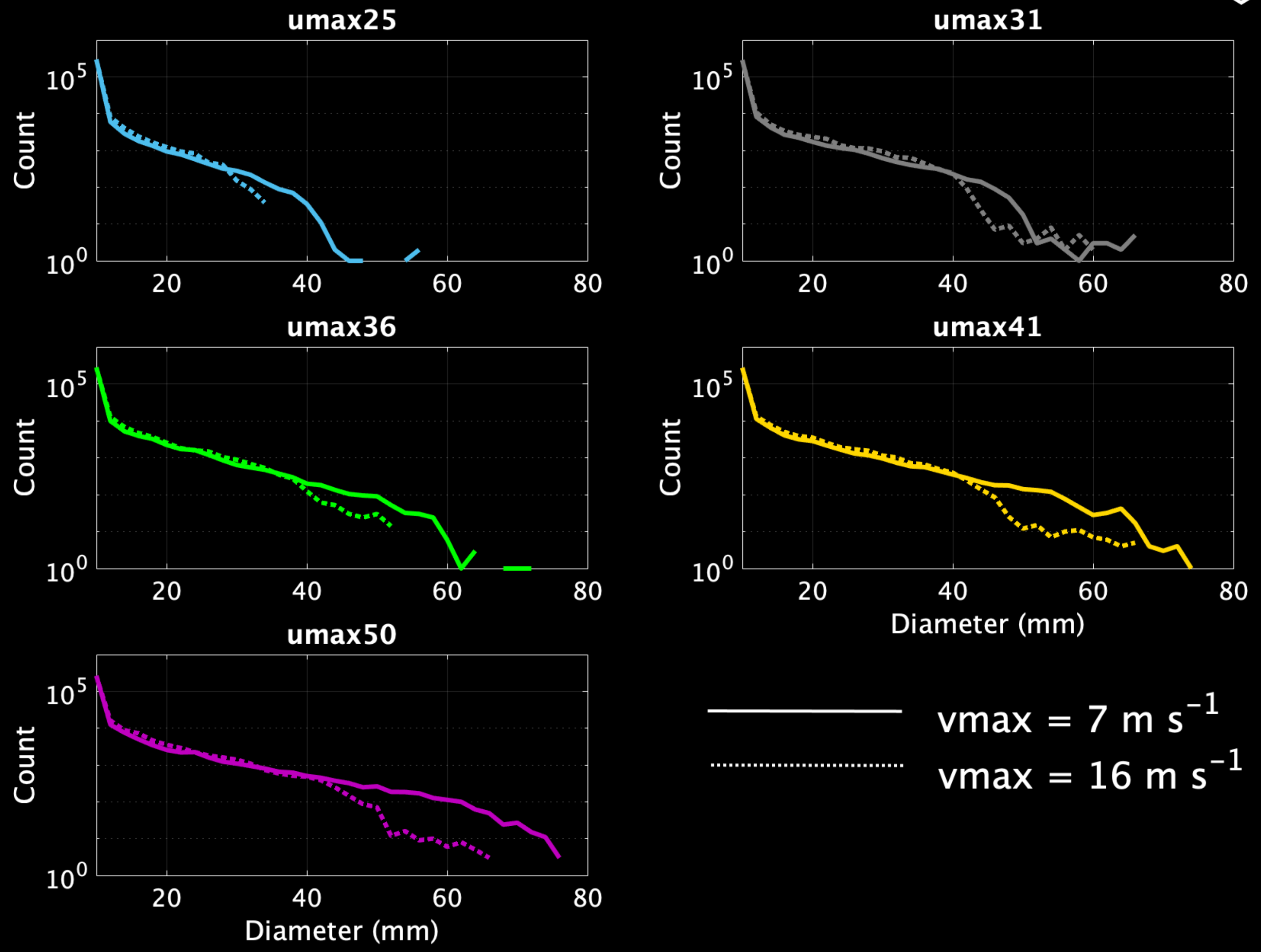


Increased deep-layer shear leads to greater amounts of and larger-sized hail

(Kumjian and Lombardo 2020)

Impact of Vertical Wind Shear





Increased low-level (meridional) shear leads to smaller hail sizes, owing to reduced residence time

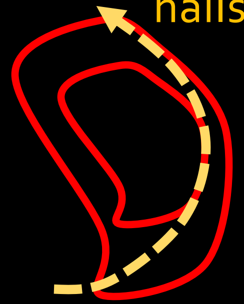
(Kumjian and Lombardo 2020)

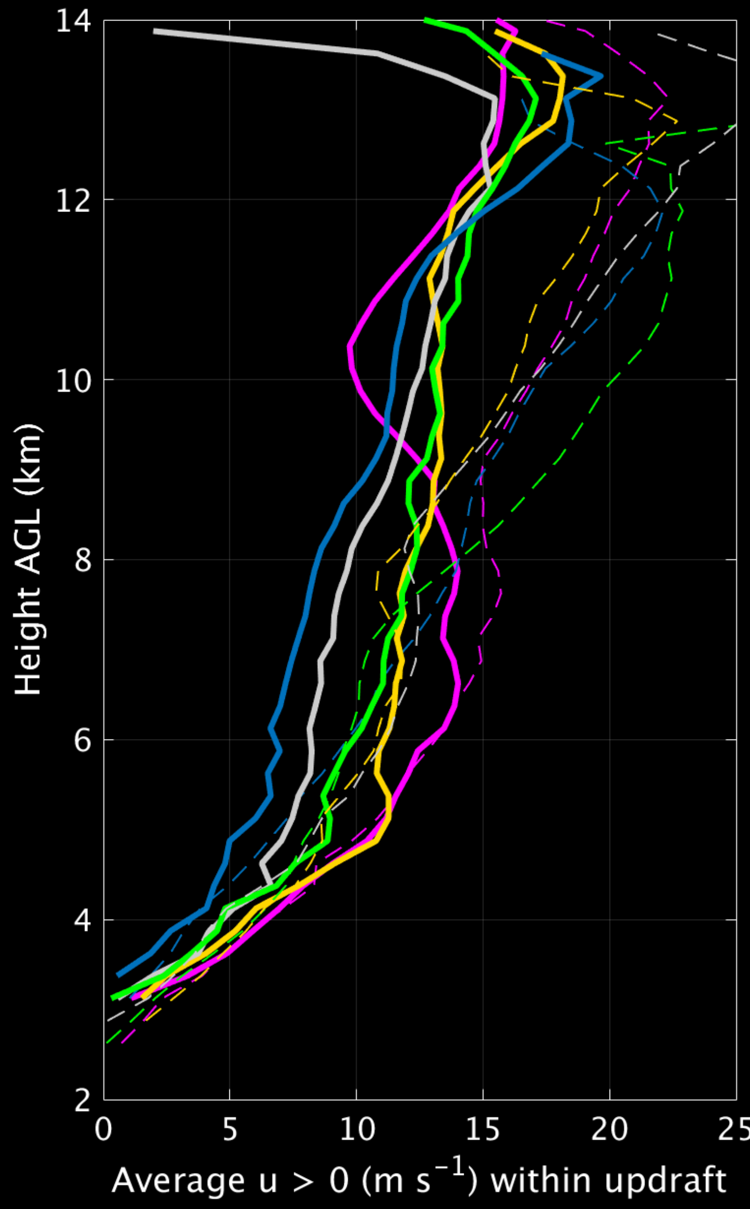
Impact of Vertical Wind Shear

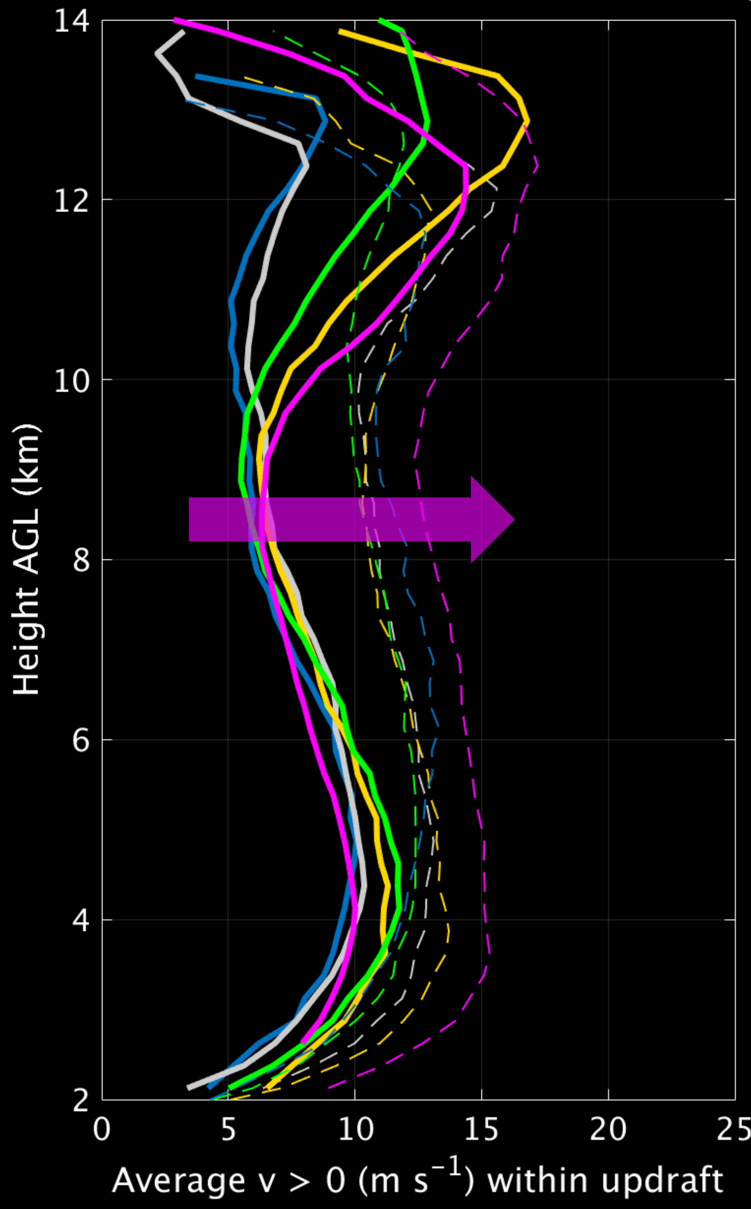
vmax = 7 m s^{-1}

vmax = 16 m s^{-1}

Greater southerly flow within the updraft advects hailstones through growth region faster

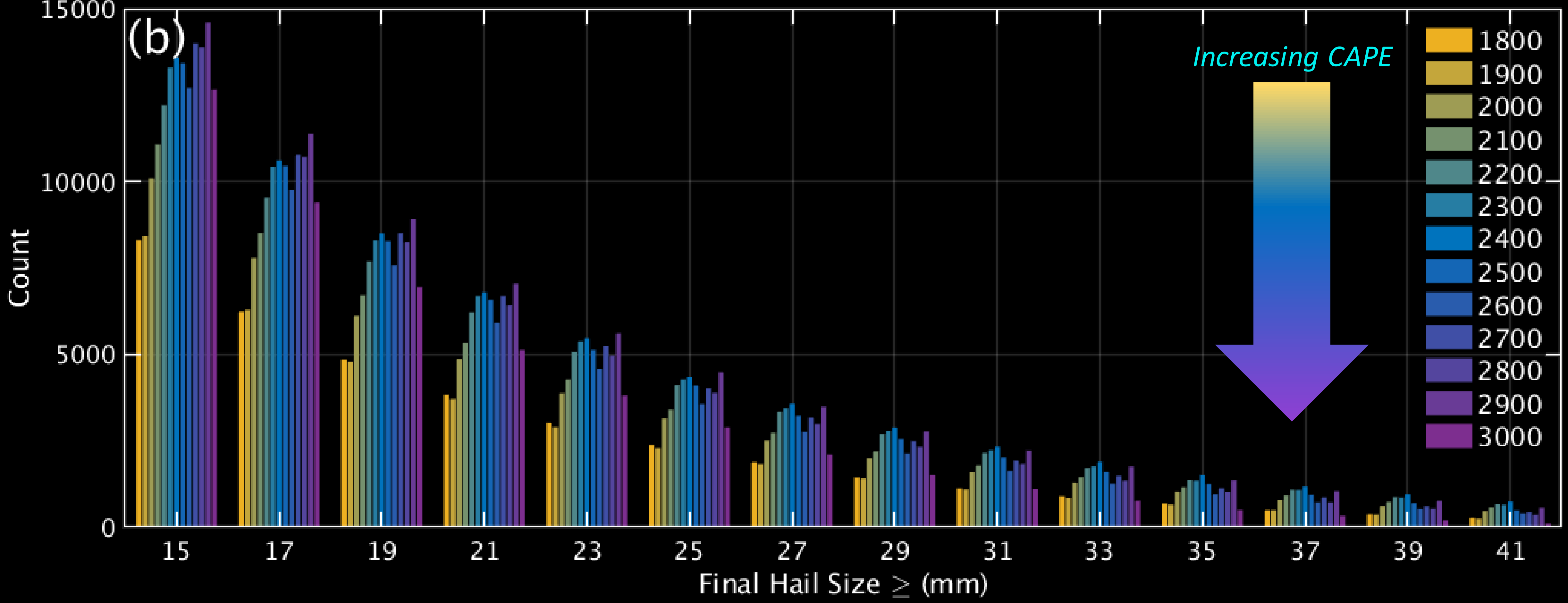






(Kumjian and Lombardo 2020)

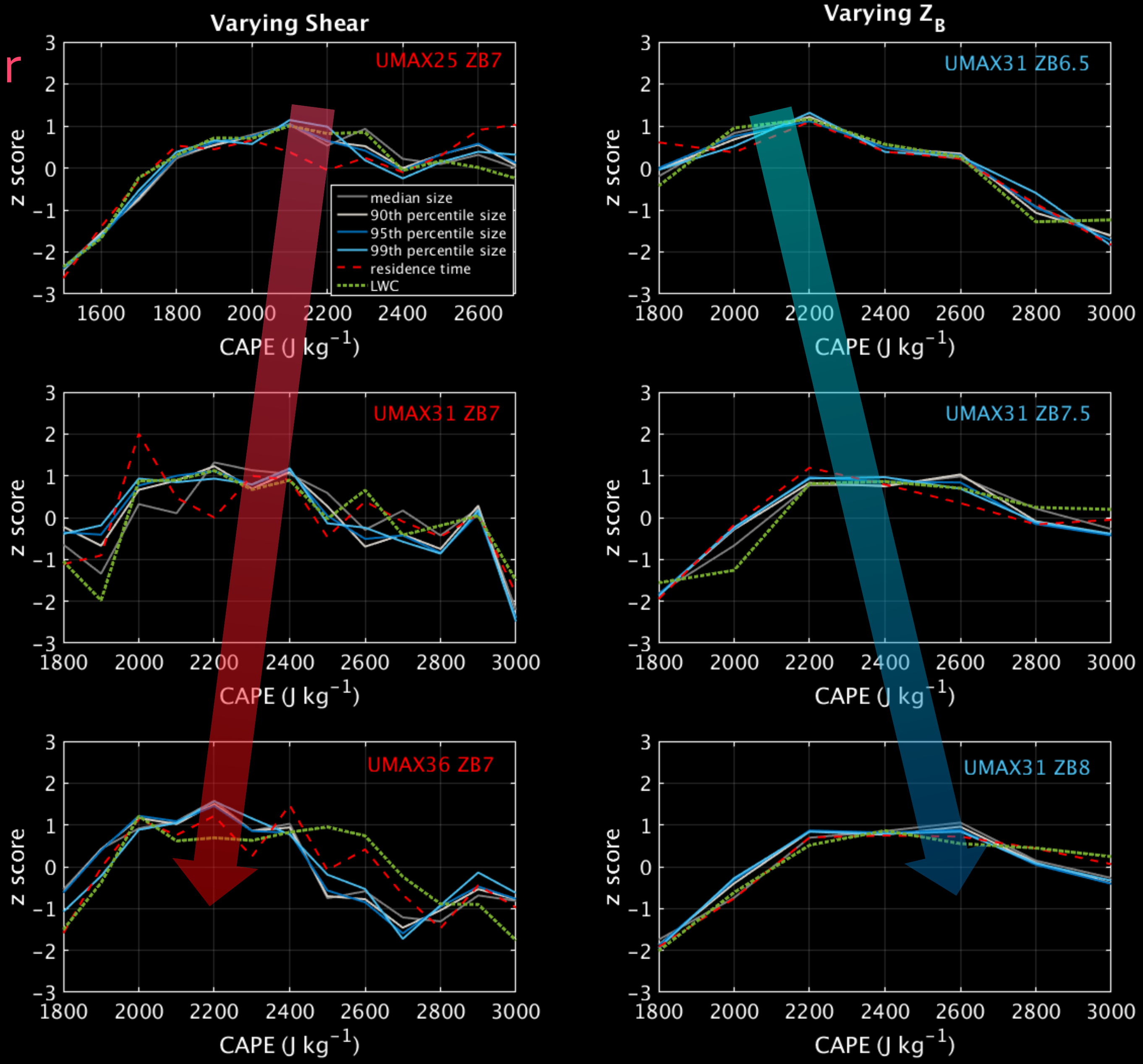
Impact of Instability



Lin & Kumjian (2022, JAS)

Impact of Instability & Shear

Increasing 0-6-km shear



"fatter" CAPE

"skinnier" CAPE

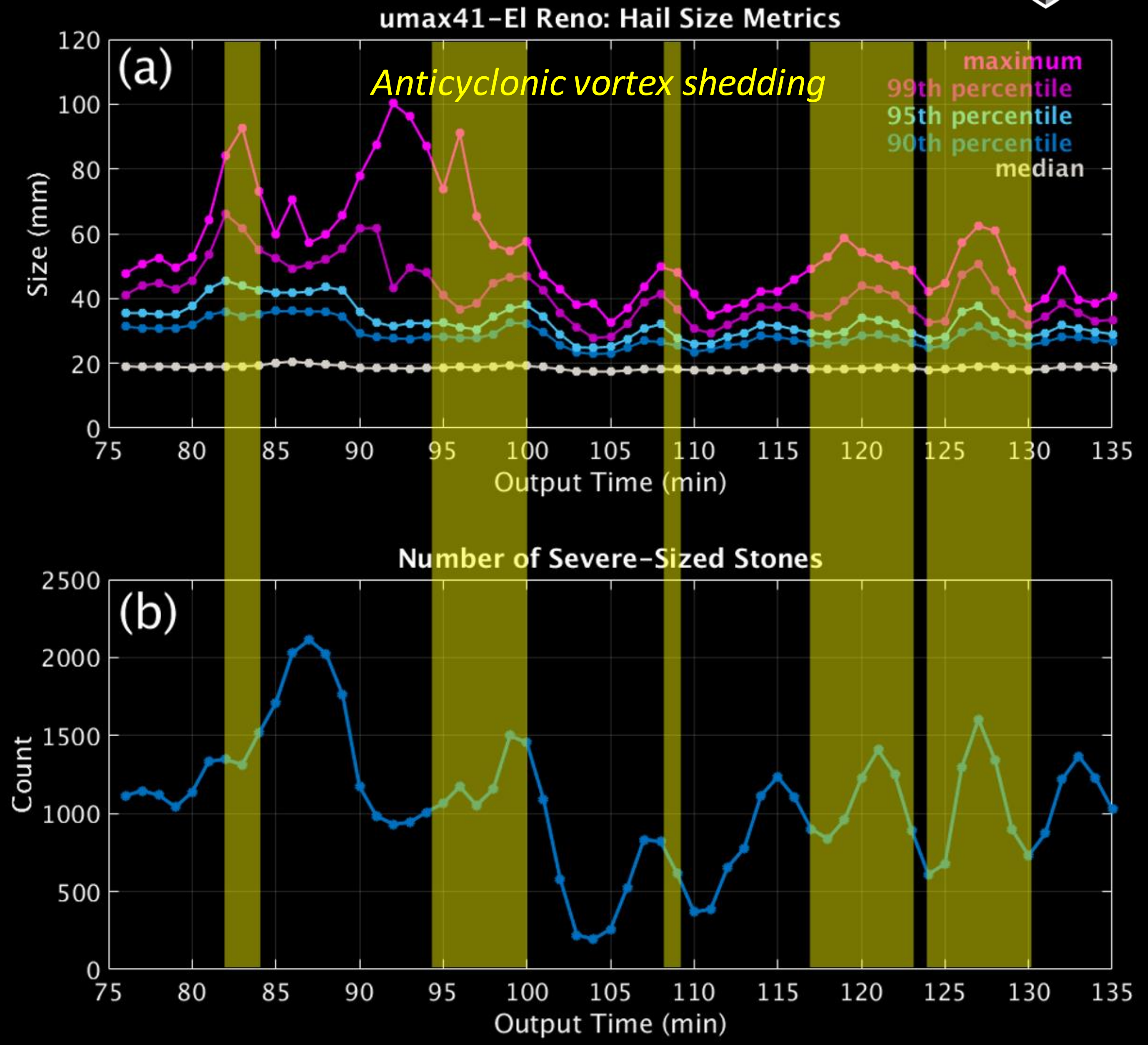
Lin & Kumjian (2022, JAS)

Impact of Storm Evolution

Simulated hail size metrics

More than doubling of max size on short timescales (<20 min)

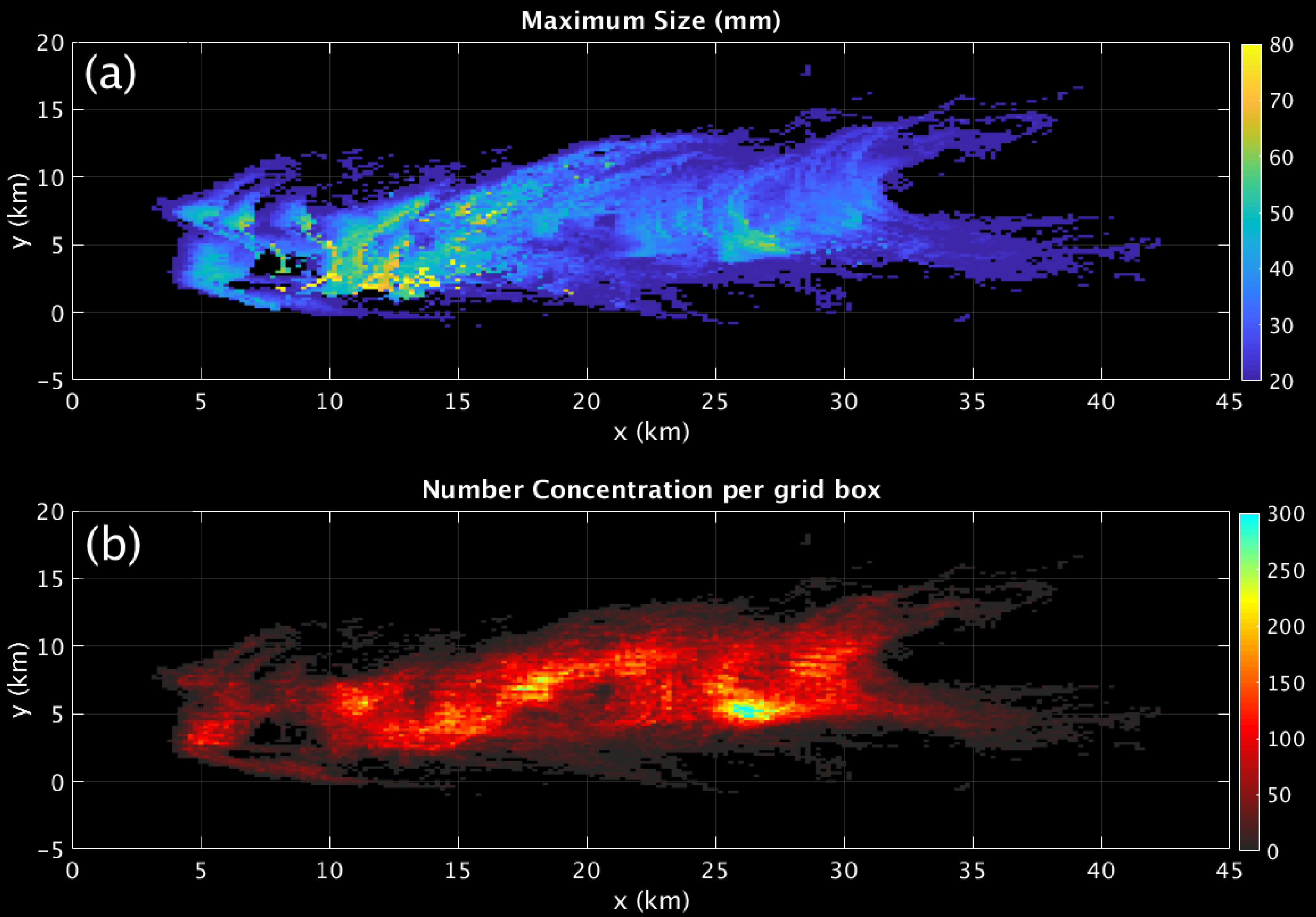
1-2 orders of magnitude difference in quantity of severe hail produced



Kumjian, Lombardo, Loeffler (2021, JAS)

Impact of Storm Evolution

Simulated hail swaths



Kumjian, Lombardo, Loeffler (2021, JAS)

Summary

- Hailstone trajectory modeling allows for **systematic exploration of environmental and internal storm controls** on hail production
- **Covariability** between vertical wind shear and instability effects on hail production **complicates developing simple environmental parameters**
- **Significant variability in hail production arises from natural storm evolution**; the details of this variability, in turn, are related to environmental characteristics.
- **Approach can be run with any stormscale NWP system; massively parallelizable.**

Thank you!

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