Does vertical velocity influence entrainment in moist thermals?

Jake P. Mulholland[1], Hugh Morrison[2], and John M. Peters[3]

1 = University of North Dakota

2 = National Center for Atmospheric Research

3 = Pennsylvania State University

Background and motivation

- Previous observational and numerical modeling studies have found an inverse correlation/scaling between in-cloud vertical velocity (w) and fractional entrainment rate (ϵ)
  - *Tian and Kuang (2016; GRL); Zhang et al. (2016; CLIM DYN); Kirshbaum and Lamer (2021; JAS)*
- Numerous cumulus parameterization schemes invoke the proposed inverse relationship between w and ϵ
  - *Lin (1999; JAS); Gregory (2001; QJRMS); Neggers et al. (2002; JAS); de Roode et al. (2012; MWR); de Rooy and Siebesma (2010; QRJMS); Tian and Kuang (2016; GRL); Tan et al. (2018; JAMES)*
- "Chicken & egg argument":
  - Does w affect ϵ?
  - Does ϵ affect w?
  - Or do both affect each other in some way?

Scientific question and hypothesis

Scientific question:

Do moist thermals with stronger *w* have smaller *ϵ-driven dilution* than moist thermals with weaker *w*? (for deep convection)

Hypothesis:

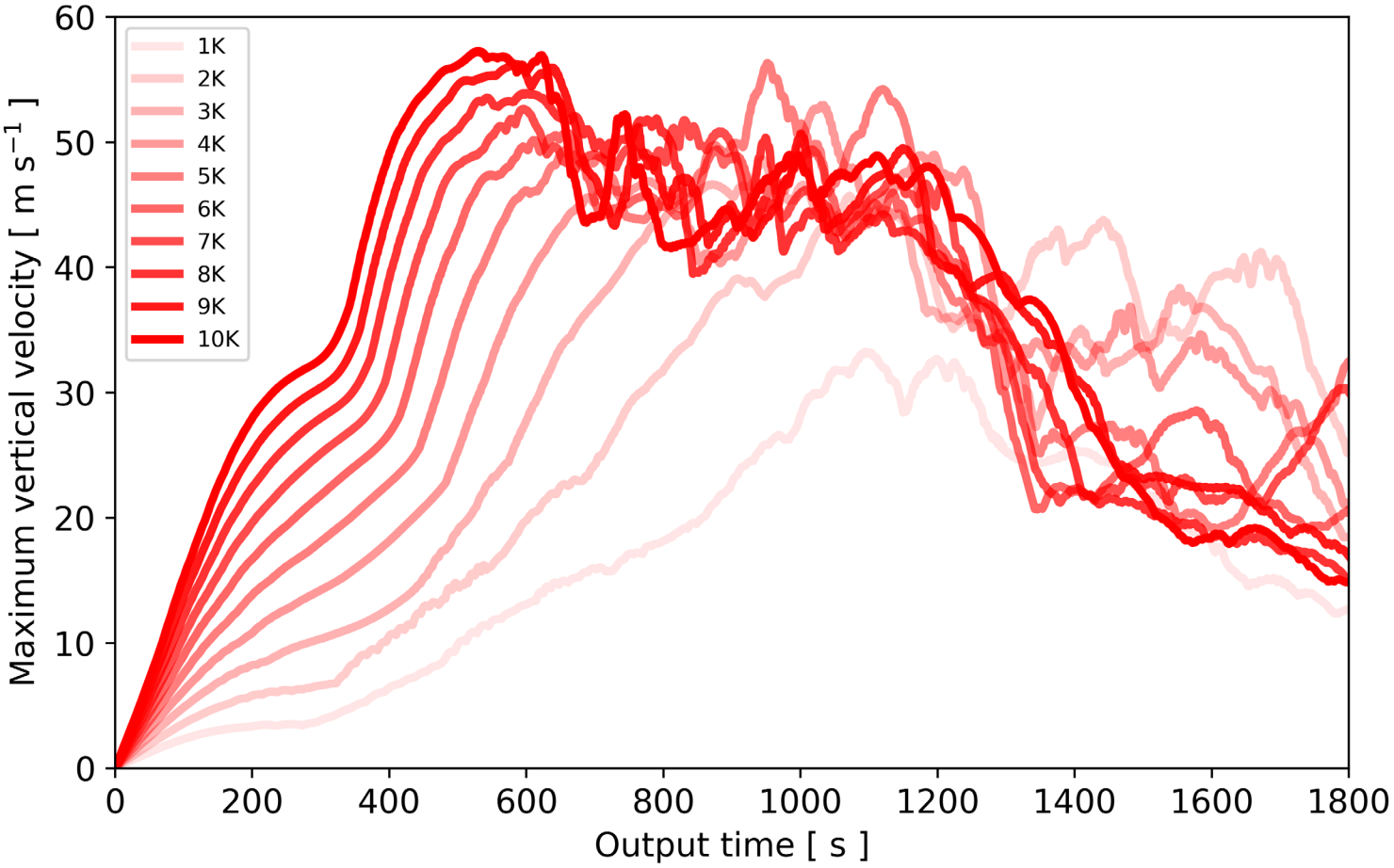
Moist thermals with stronger *w* have less time to be exposed to the free troposphere, and thus, have smaller *ϵ-driven dilution*.

- Akin to "core-exposure effect" as discussed by *Drueke et al. (2021; ACP)*

Numerical modeling framework

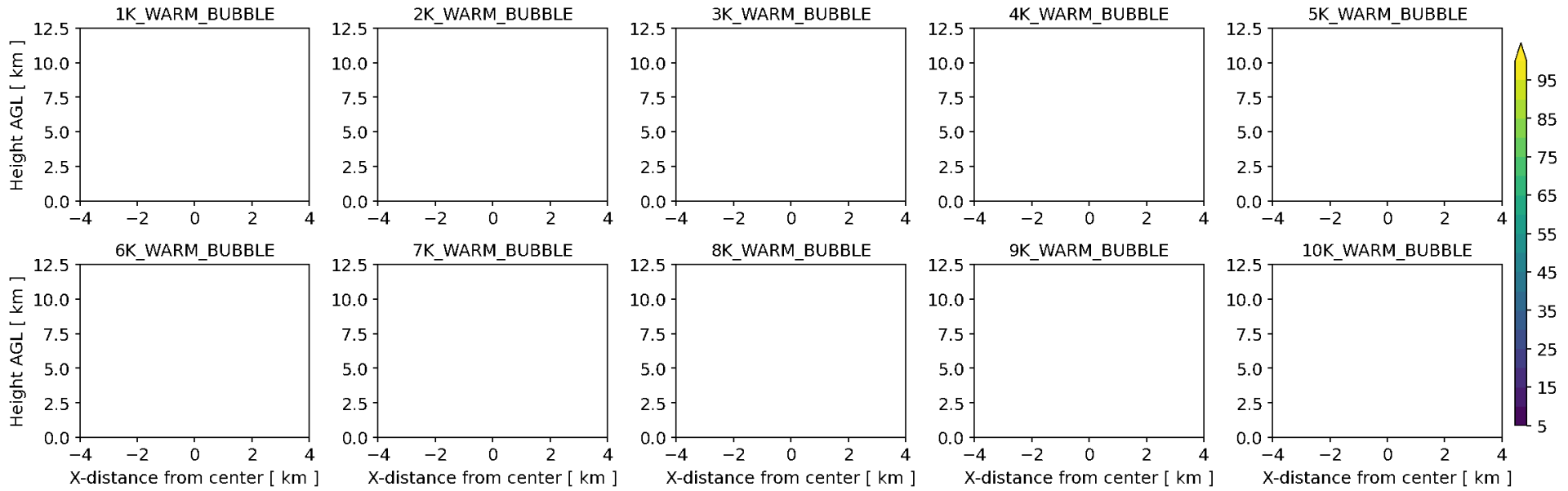
- Idealized “single cloud” simulations using Cloud Model 1 (CM1)
- No winds; *Weisman and Klemp (1982; MWR)* thermodynamic profile
- “Warm bubble” convection initiation technique
  - Systematically alter potential temperature perturbation to vary *w*
  - Horiz. radius = 2 km; Vert. radius 1.5 km; Centered at 0.5 km AGL
- 100 m grid spacing in all directions (25 x 25 x 25 km^3 domain)
- Morrison two-moment microphysics scheme (“ihail” = graupel)
- Smagorinsky turbulence scheme
- Initial +/- 0.5 K potential temperature perturbations domain-wide
  - “Spin-up” turbulence spectrum similar to *Peters et al. (2019; JAS)*
- 30-min simulations; 30-s output
- Passive tracer (PT) within 0-1 km AGL high-CAPE/low-CIN layer

Warmer warm bubble = stronger *w*?



UNIVERSITY OF NORTH DAKOTA

Stronger *w* = smaller *ϵ-driven dilution*?



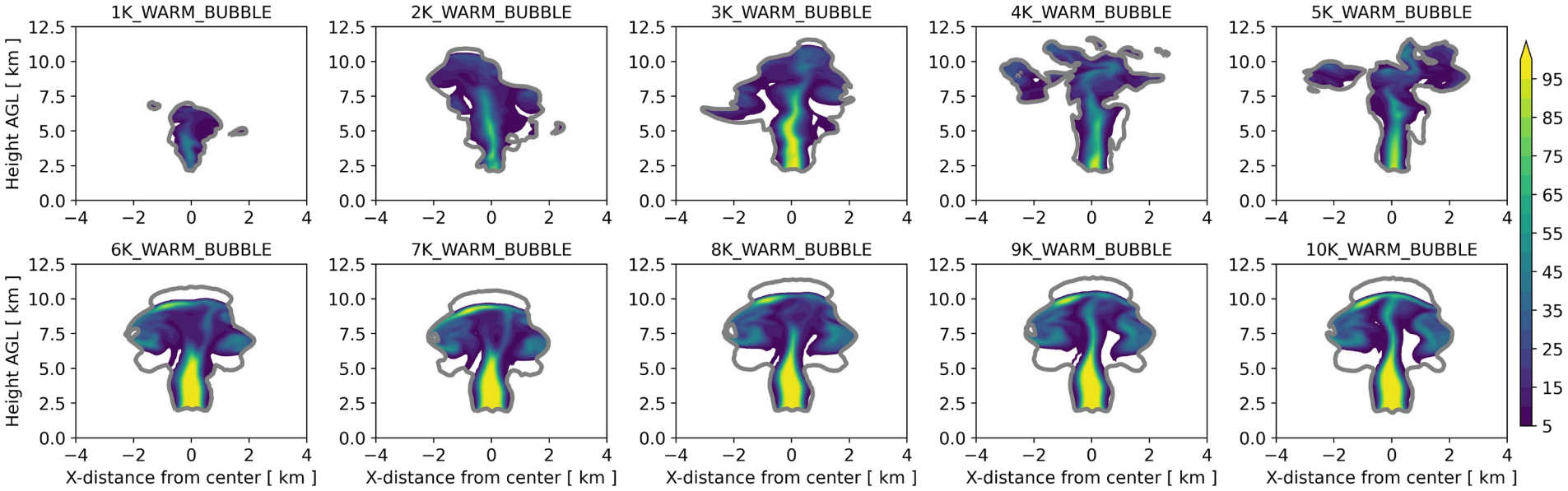
Grey contour = 20 dBZ

Shading = Passive tracer conc. [%]

UNIVERSITY OF NORTH DAKOTA

Stronger *w* = smaller *ϵ-driven dilution*?

@ time of w_{MAX}

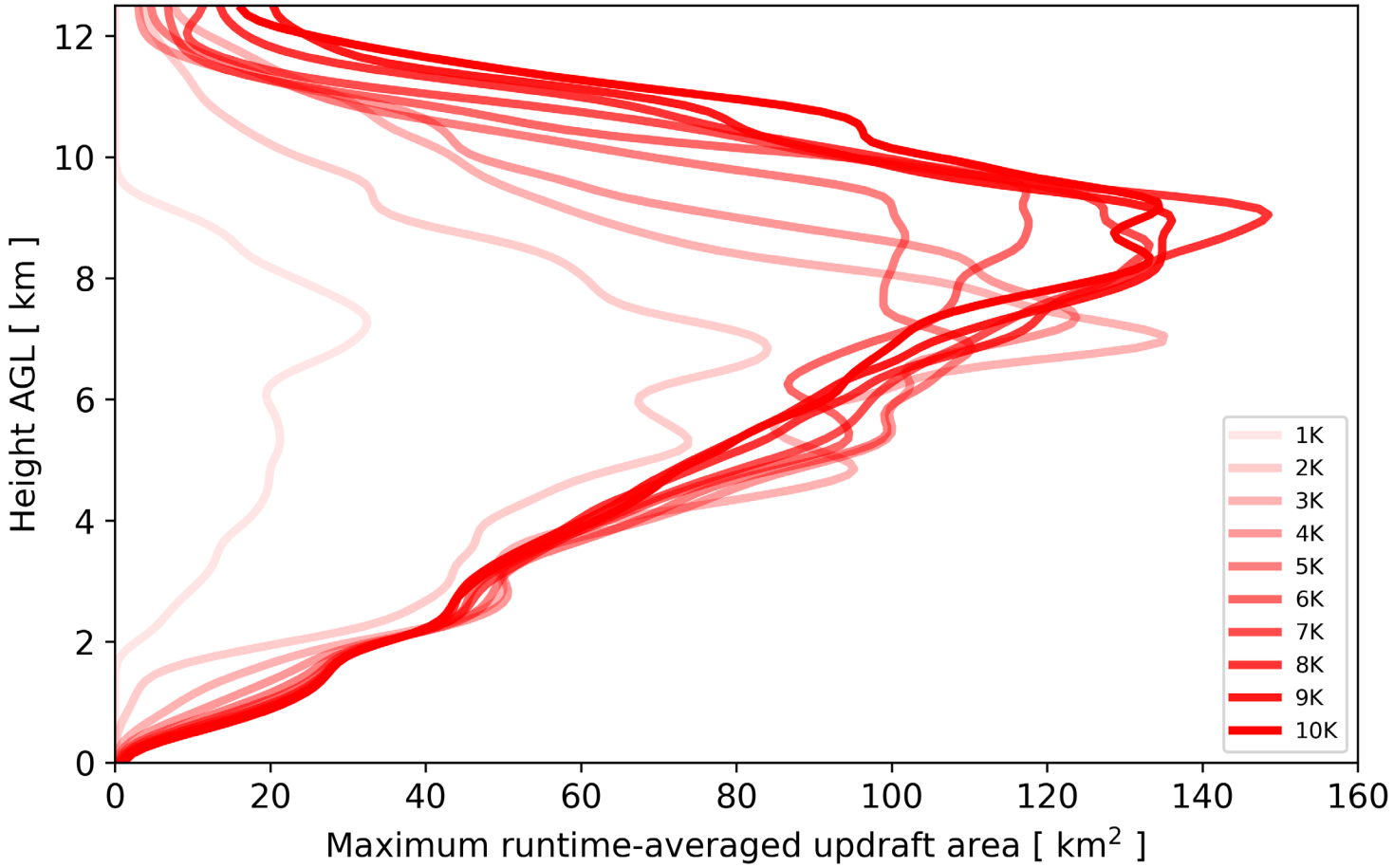


Grey contour = 20 dBZ

Shading = Passive tracer conc. [%]

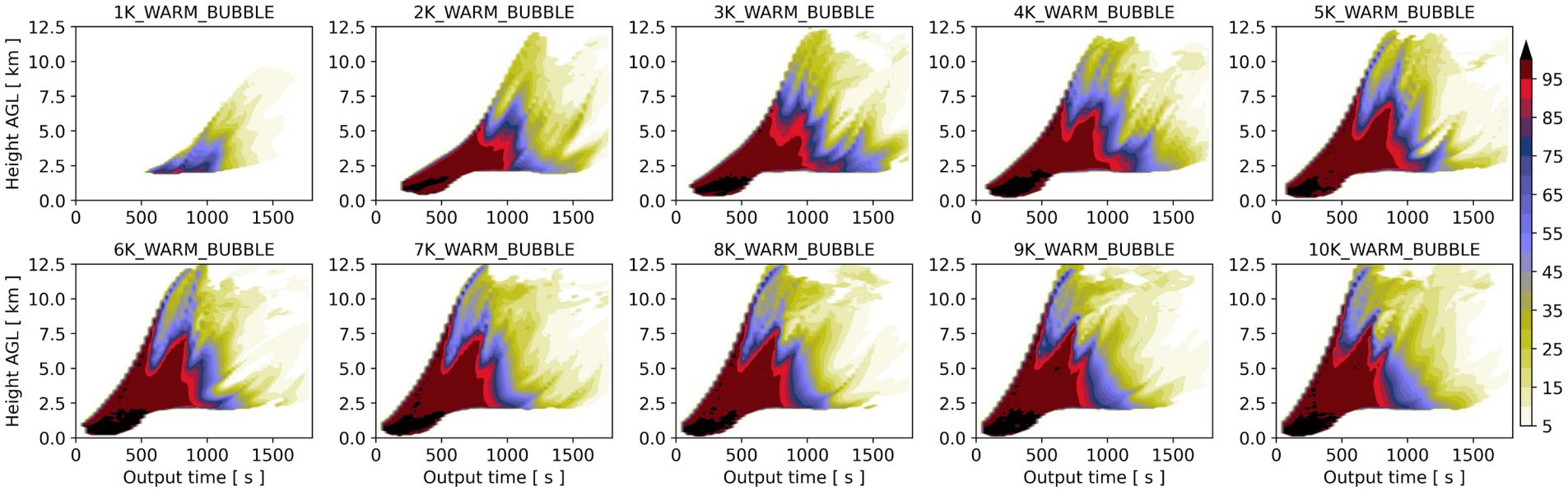
UNIVERSITY OF NORTH DAKOTA

Does updraft width change?



UNIVERSITY OF NORTH DAKOTA

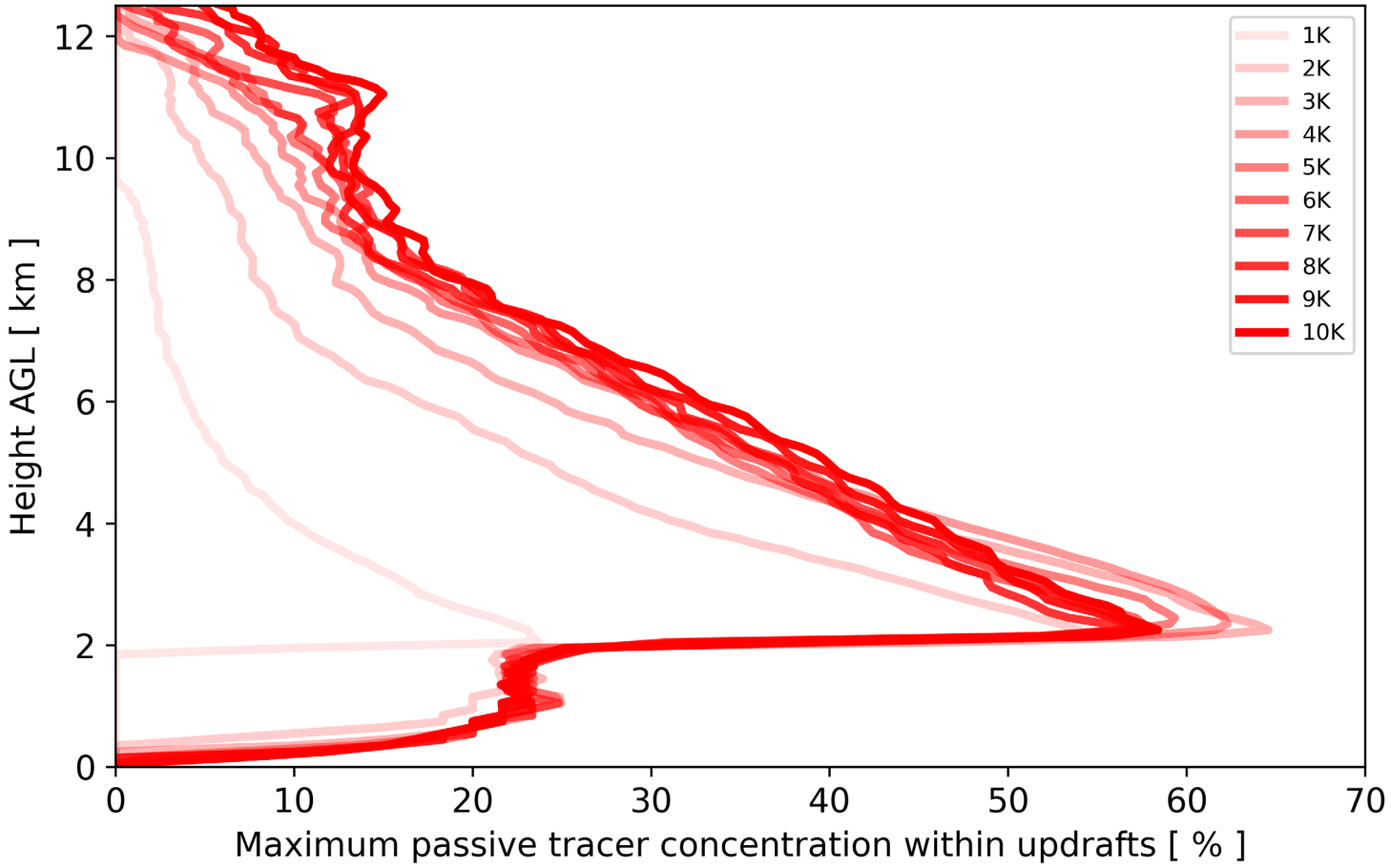
Stronger *w* = smaller *ϵ-driven dilution*?



Shading = Max. passive tracer conc. [%]

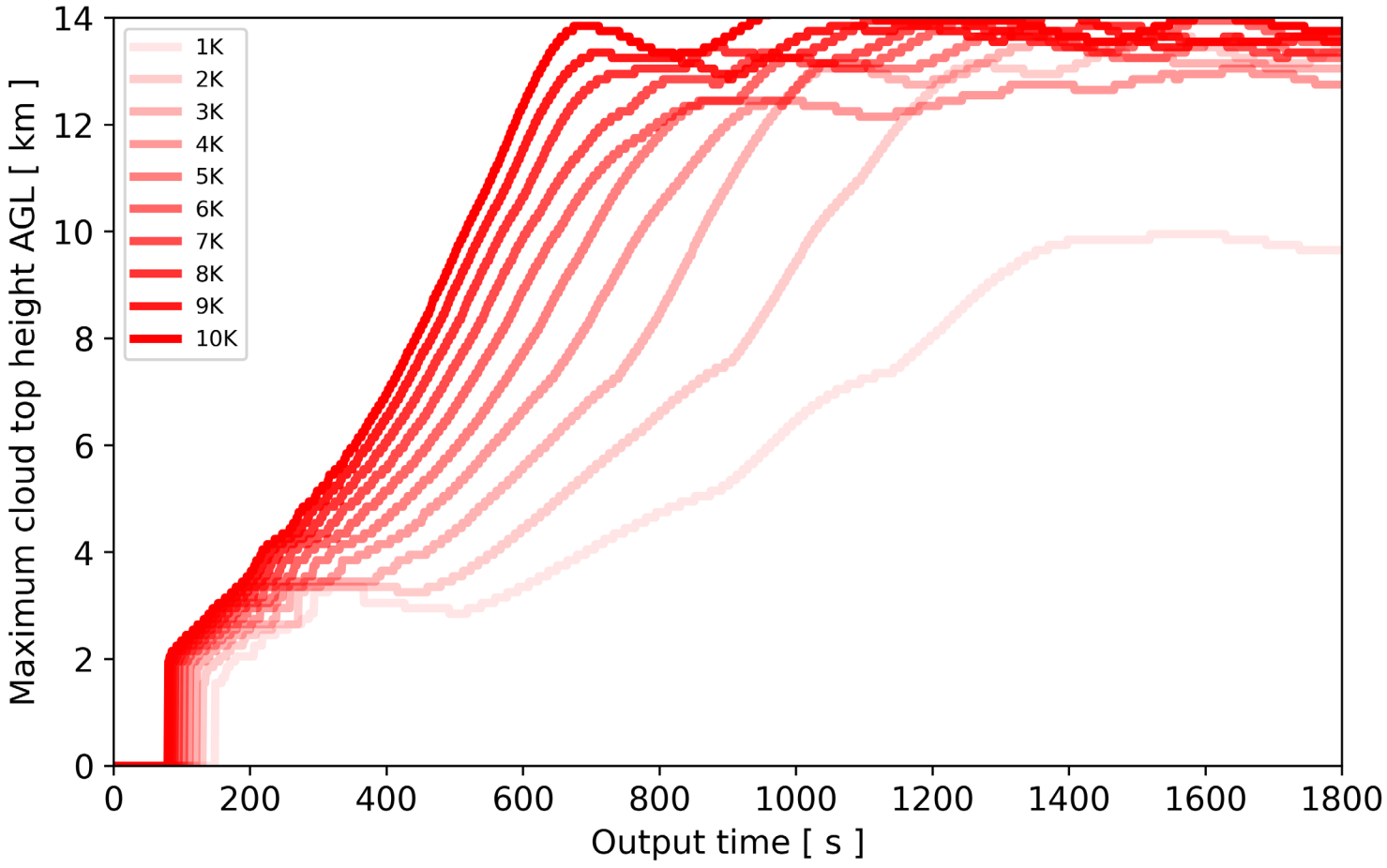
UNIVERSITY OF NORTH DAKOTA

Stronger *w* = smaller *ϵ-driven dilution*?



UNIVERSITY OF NORTH DAKOTA

Smaller *ϵ-driven dilution* = taller cloud tops?



UNIVERSITY OF NORTH DAKOTA

Conclusions and discussion

- Apparent inverse scaling between w and ϵ holds true at weaker w magnitudes
  - However, updraft width also increases ➔ may also explain decreasing ϵ
- At stronger w magnitudes, inverse scaling between w and ϵ vanishes
  - Updraft width approximately constant

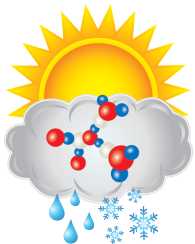
- LOTS of caveats here…
  - Enough time for turbulence to “spin up” in these short-fused simulations?
  - Warm bubble convection initiation technique realistic?
  - Only one thermodynamic environment with no winds

Future work

- Examine inverse scaling between w and ϵ with various convection initiation techniques to build statistical robustness:
  - Updraft nudging (*Naylor and Gilmore 2012; MWR*)
  - Forced convergence (*Loftus et al. 2008; MWR*)
  - Momentum forcing (*Morrison et al. 2015; MWR*)
  - Surface fluxes (*Morrison et al. 2022; JAS*)
- Attempt to tease out impact of updraft width on the inverse scaling between w and ϵ
- Additional simulations where…
  - Condensate loading term in the microphysics scheme is altered to vary w "less artificially"
  - Precipitation formation and ice processes removed to simplify things
  - Stability of free troposphere is altered

Thank you for your attention!

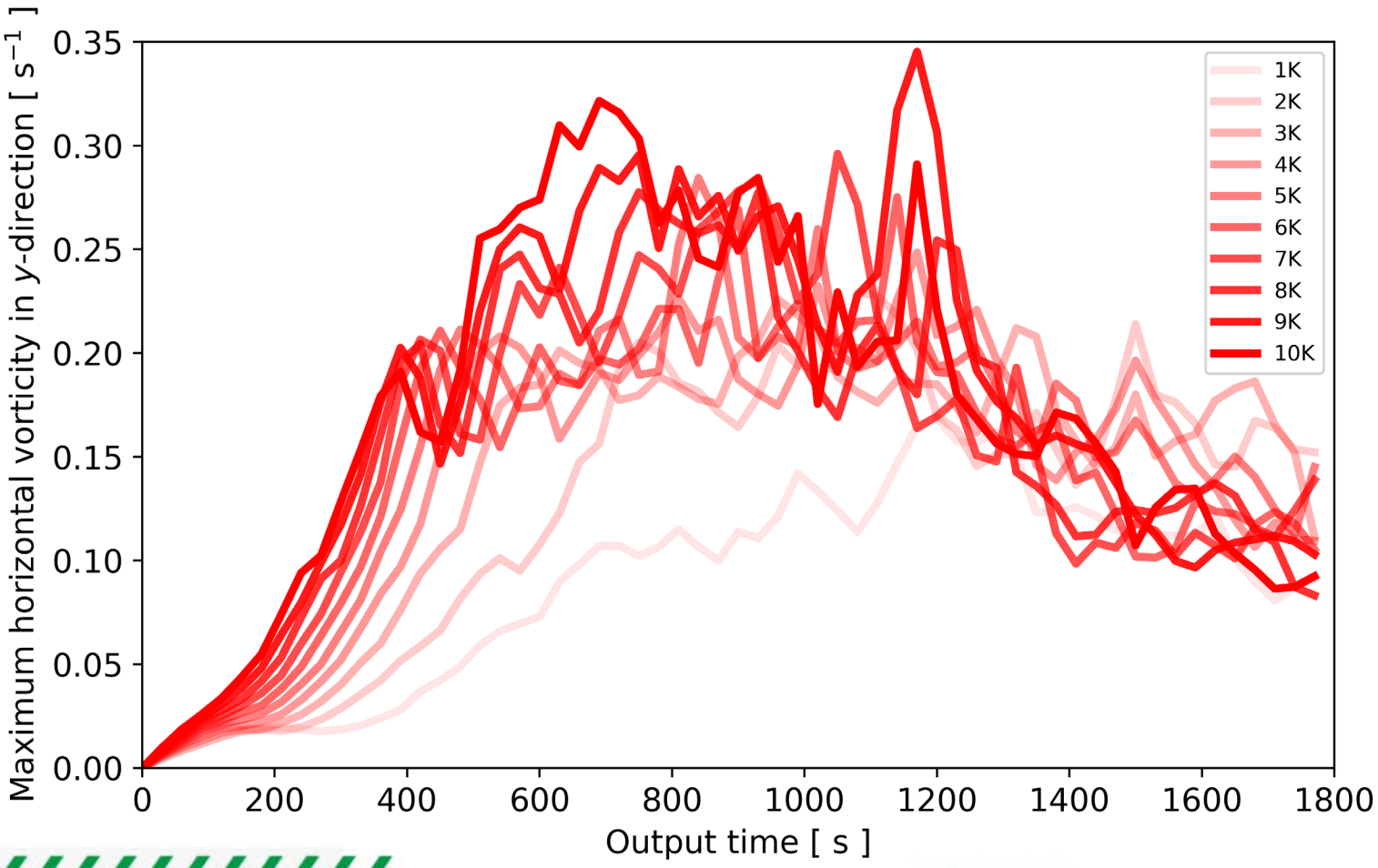
jake.mulholland@und.edu



ASR
Atmospheric
System Research

UND UNIVERSITY OF NORTH DAKOTA

And the toroidal circulations?



UNIVERSITY OF NORTH DAKOTA